

GENERAL SCIENCE

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PREFACE

MORE than a dozen years' experience in teaching General Science has convinced us that any course for the study of this subject must have two main objectives. It must provide the opportunity for the pupils to acquire a body of scientific knowledge so that they can study and analyse their environment, and it must, by continued example, develop in them a thorough appreciation of the importance and nature of the Scientific Method so that they are capable of applying it to new investigations in later life. The cause and prevention of disease, the study of nutrition, the significance of soil studies, the study of inheritance and evolution all demonstrate the need for treating General Science as a whole subject if our pupils are to appreciate to the full the interrelations between the parts of their environment and themselves. We believe that this side of science has particular value in helping to build a better society.

The criticism is often levelled at General Science that it is superficial and does not make scientists. It is this criticism which we have attempted to meet by providing a course which gives full accounts of investigations and discusses the reasons for carrying them out and the nature and limitations of the inferences that can be drawn from them.

The book is designed to cover a four or five years' course up to the standard of School Certificate. We have included many experiments, and have introduced them, not as arid academic examples of particular phenomena, but as essential steps in the development of our investigations so that, as far as possible, the pupils are guided in finding out for themselves. Instructions for the proper performance of every experiment are given. We believe that by doing so we serve two purposes: we provide laboratory directions for the pupils and also assist those teachers who, because of their lack of training in one branch of science, are not familiar with the conduct of experiments

PREFACE

in that branch. We make no apology for having included more experiments than can usually be carried out in the time allotted to science in the school curriculum, since by doing so we give an opportunity for variation in the course. Although the book meets the demands of a School Certificate course we have not hesitated to go outside the syllabus when an interesting link could be made.

Our main aim has been to write a book which treats General Science as a whole subject and, at the same time, so to stress the importance of accurate observation and logical discussion, that if the pupils specialize later in one particular branch they will be able, from their training in General Science, to approach new problems in a proper scientific manner. For those who do not become scientists the course provides a survey of their environment which will open their eyes to the relationships which exist between many phenomena in the world.

July 1947

S. W.
A. W. P.

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PART I

I. INTRODUCTION

MOST of us are led by a natural curiosity to try to discover how things work and of what they are made. Unless this investigation is made systematically we shall not get very far; but if we observe accurately, experiment carefully, and reason correctly, we may hope to understand better the world in which we live.

As we look around we notice that all matter is either living or non-living. A dog is alive, and so is a tree; but a stone is not alive, and so far as we know has never been alive. The stone is not merely dead; it has never lived. It is different from a dead dog which has once lived. There are obvious differences between non-living matter and living things.

LIVING AND NON-LIVING THINGS COMPARED

Living things can make movements by themselves, non-living things cannot. The position of a stone cannot change unless some force outside the stone causes it to move. A living thing can move without the aid of an outside force. A dog can change its position at will. A tree cannot walk about, and seems to be swayed only by forces outside itself, but we shall see later that a tree can and does move its parts in ways not possible for a stone.

If you touch a dog it will react in some way, perhaps by snapping at you or going away from you. If a stone is touched it does not react in any such way. Living things are capable of being stimulated from outside themselves and of reacting to the stimuli. The stimuli may be of various kinds such as light, heat, or sound, but all living things are not capable of reacting to all kinds of stimuli, though it is characteristic of all living things that they are capable of receiving and responding to some stimuli. This power is called *irritability*. (We often speak of a person being 'irritable' when he is easily offended. Actually he is too sensitive to outside stimuli, and responds to them too freely.) Non-living things are not irritable.

Living things respire, non-living things do not. In ourselves and other animals which make movements when they respire we speak of it as breathing, but as all plants and a large number of animals do not make breathing movements, it is better in all cases to speak of this process as *respiration*.

Living things require food to transform into the substance of their bodies and to provide energy for their activities. This power of feeding or nourishing is called *nutrition*.

A living organism has the power of *growth*. If a crystal of alum is suspended in a solution of alum it will become larger and have a shape characteristic of alum crystals. It 'grows' because some of the alum from the solution is deposited on the crystal. Alum is merely added to alum. A cow eats grass which is transformed into muscle, fat, bone, and milk. There is a great difference between these two ways of 'growing'. We can say that the cow eats and grows, whereas the crystal increases in weight by an accumulation of more of the same substance.

As a result of their activities living things have to get rid of waste substances which are formed. This is known as *excretion*.

Living things are able to produce young which in time grow like their parents. Trees produce seeds, hens produce eggs from which chickens hatch, cows produce calves, but stones and other non-living things do not reproduce themselves.

Thus the characteristics of living things are: Movement, Irritability, Respiration, Nutrition, Growth, Excretion, and Reproduction. During the course of our work we shall study these in greater detail, but meanwhile you should get into the habit, when examining a plant or animal, of noting which of these characteristics are obvious or not.

Again we shall try to find out how living organisms have adapted themselves to make the best use of these characteristics in their own particular environment, thereby making their existence easier. Further, we shall see how Man, by reason of his more highly developed brain, has made use of other living organisms and non-living things to this end; e.g. how he has bred animals and cultivated plants to give him food, and invented machines to do his work.

PLANTS AND ANIMALS

We have mentioned two kinds of living things, plants and animals. It is difficult for some people who have not studied plants to believe that they are alive in the same sense that animals are alive. We shall see that this is true. The differences between plants and animals are more obvious than the resemblances between them, but we must avoid getting our ideas about plants and animals only from those we commonly see around us. We can all see differences between a cabbage and an elephant, but there are some very simple living things, mostly so small as to be microscopic, which cannot be classified definitely as animals or plants, for they have some characteristics of both. Generally animals and plants differ chiefly in:

- (1) the ways in which they move from place to place (plants usually remain fixed to one spot);
- (2) the way in which they obtain their food.

The second is the more important, for some animals remain fixed, while a few plants actually swim. There are other important differences but these must be left until we have examined some plants and animals.

THE DEPENDENCE OF LIVING THINGS ON WATER AND AIR

Living things cannot live for long without water and air. We have seen plants wilt and die when short of water, and we know that all the animals we commonly see around us must have both air and water. We cannot hope to understand how plants and animals live unless we know their relations to water and air. If we wish to learn about living things we must first study the air and water, so important to them and to us.

QUESTIONS

1. What are the essential differences between living things and non-living things?
2. State clearly the difference between the 'growth' of a crystal and the growth of an animal.
3. What are the main differences between plants and animals? Illustrate your answer with examples.

II

PRELIMINARY STUDY OF WATER WATER

WE shall first study water rather than air because it is much more easily handled. We already know much about it. It is the most familiar liquid in our experience. It falls on us from the skies, runs in streams and rivers, forms ponds, lakes, and oceans. The greater portion of the earth's surface is occupied by water. Simply by keeping our eyes open and observing the effects of water on the things around us we can learn much, especially if we observe carefully. We can also learn about water by handling it and by trying to do things with it.

SOLUTIONS AND SUSPENSIONS

Expt. 1. Stir some common salt in water. The salt disappears. It dissolves in the water. The resulting liquid is called a solution of salt in water. The salt is soluble in water. We say that water is a solvent for salt. The substance dissolved in the solvent, in this case salt, is called the solute.

Expt. 2. Stir a very little powdered chalk in a large beaker of water. The chalk does not disappear. The chalk is insoluble in water. It does not dissolve. The resulting liquid is called a suspension of chalk in water. If the suspension is left for a time, most of the chalk falls to the bottom as a sediment.

Make a list of substances which are (1) soluble in water, (2) insoluble in water. If you do not know whether a substance is soluble or not, try it, using a small quantity of the substance and a comparatively large quantity of water.

Expt. 3. Put some salt solution in an evaporating basin and heat it. The water disappears, and the salt remains behind. The water has changed from liquid water to water vapour. It has *evaporated*, that is, has changed from a liquid to a gas (or vapour).

Expt. 4. Allow the suspension of chalk in water to stand a long time until all the chalk is at the bottom of the vessel. Pour off the water from the chalk. This process is called decanting. The chalk may be separated from most of the water left by drying on blotting paper.

Expt. 5. Fold a filter paper and fit it into a filter funnel (Fig. 1). Pour into the paper a suspension of chalk in water. The chalk

remains on the filter paper and the water passes through. This process is called filtration. What remains on the filter paper is called the residue. What passes through is called the filtrate (Fig. 2).

Expt. 6. Filter a solution of salt in water. Does anything remain on the filter paper? What passes through the filter paper? To recover the solid from a liquid in a suspension we decant or filter. To recover a solid dissolved in a liquid we evaporate the liquid.

Water is not the only solvent although the most important. Not only will it dissolve more solutes than any other solvent,

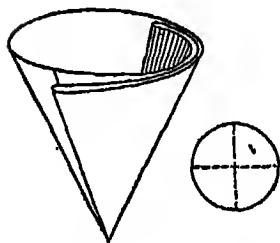


FIG. 1. Folding a filter paper.

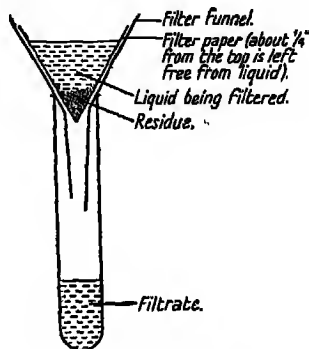


FIG. 2. Filtering a liquid.

but it is the solvent in the bodies of living plants and animals for food, thus enabling transport and digestion to take place.

Expt. 7. Use water, benzene, and carbon disulphide as solvents to try to dissolve salt, iodine, paraffin wax, and sulphur. As benzene and carbon disulphide are extremely inflammable great care must be taken with these liquids. The liquid, or vapour from the liquid, must not come near a flame. The tubes containing these liquids may be warmed by holding them in a beaker of warm water.

Methylated spirit is used for dissolving shellac in the manufacture of french polish. It is also used to dissolve iodine, together with a few crystals of potassium iodide, in the preparation of 'tincture of iodine'. Benzene, petrol, and ether dissolve fats and oils, and are therefore used for 'dry cleaning'. 'Rubber solution', used for mending punctures, is made by dissolving rubber in benzene.

THE SEPARATION OF MIXTURES

The fact that some substances are soluble and some insoluble in a liquid may be used to separate them.

Expt. 8. To separate a mixture of salt and chalk. Add a little of the mixture to water in a beaker and stir. What happens to the salt? What happens to the chalk? Filter. Of what does the filtrate consist? What is the residue? Wash the residue free from salt water by passing water through the filter three or four times. Scrape the wet chalk on blotting-paper until as much as possible of the water is removed. Evaporate the filtrate. What is obtained?

Expt. 9. To separate a mixture of iron filings and sulphur. We take advantage of the fact that sulphur is soluble and iron filings insoluble in carbon disulphide. (Do the work in a fume cupboard because carbon disulphide is poisonous, inflammable, and has an unpleasant smell.) After adding carbon disulphide to the mixture in a test-tube, shaking and allowing to settle, decant into a watch-glass. Allow the carbon disulphide to evaporate. This it does quickly as it is very volatile (easily vaporized). Crystals of sulphur are left on the watch-glass. Shake the iron filings with more carbon disulphide to dissolve any sulphur that may be left. Decant. Repeat this process until the iron filings are free from sulphur.

SATURATED SOLUTIONS

Expt. 10. Add a little copper sulphate to some water in a beaker and stir. The copper sulphate dissolves. Add more copper sulphate. If this dissolves add still more, until no more will dissolve. We have now a *saturated solution* of copper sulphate in water. Warm the beaker over a bunsen burner. The remaining copper sulphate dissolves. Add more copper sulphate until no more will dissolve. We have now a hot saturated solution, whereas before we had a cold saturated solution. Decant the hot saturated solution into two portions in separate beakers, *A* and *B*. Cool the solution in *A* quickly by allowing cold water to run on the outside of the beaker. Stir while cooling. Small crystals of copper sulphate appear. Decant, and dry the copper sulphate crystals formed by scraping them over fresh sheets of blotting-paper. Examine them under a lens or microscope. Can you say why the crystals came out of the solution on cooling?

Expt. 11. Allow the hot saturated solution in *B* to cool slowly. Note that the crystals formed are much larger than those formed in the previous experiment. Select the largest crystal that seems well shaped and undamaged. Suspend it in a cold saturated solution of copper sulphate for a few days. Watch it increase in size from day to day. What causes it to 'grow'? What causes the copper sulphate to

come from the solution? What must be happening to the water of the solution all the time? What effect will this have on the amount of copper sulphate that can remain in solution?

These experiments should be repeated using other substances, such as alum and saltpetre. Both large and small crystals should be obtained. Examine and draw the crystals.

Most, but not all, substances are more soluble in hot water than in cold. Common salt is not much more soluble in hot water than in cold. For this reason it is not a good substance to use in these experiments. A few substances, like slaked lime, are more soluble in cold water than in hot.

PURIFICATION BY CRYSTALLIZATION

It is found that if impure substances are crystallized, as in Experiment 10, and small crystals obtained, the latter are purer than the original crystals. If now the small crystals are recrystallized several times, after each recrystallization there is an increase of purity. A high degree of purity may be obtained in this way.

CRYSTALLIZATION IN NATURE

In various parts of the world huge deposits of crystals are found. Common salt is found in Cheshire and in many other parts of Europe and America. Chile saltpetre is found in enormous quantities in Chile, and there are many other deposits of various crystalline substances. These have been deposited naturally, in much the same way that we obtain crystals by slow evaporation in the laboratory. Perhaps an expanse of water containing dissolved substances becomes isolated from other water either by earthquakes or by the slow rising of the land. Then slow evaporation begins, and if the water is not replaced by streams the volume of the water decreases. This causes the solution to become more concentrated. At length the solution becomes saturated for a particular substance and further evaporation causes the crystals to be deposited. Finally all the water is evaporated and the deposit of crystals remains. Further earth movements may cause the crystals to be buried under the ground.

DISTILLATION

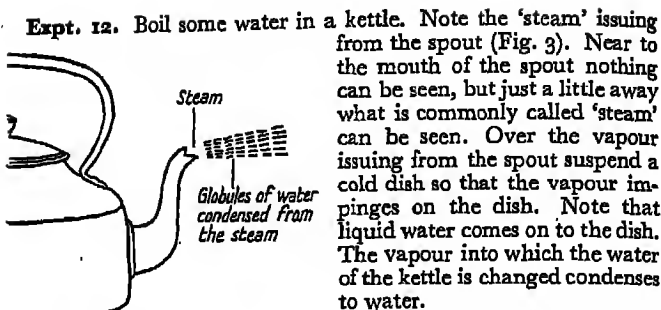


FIG. 3. Distillation of water in a kettle.

Condensation is the changing of a vapour to a liquid. Steam

is invisible. That is why nothing can be seen just at the mouth of the spout of a kettle in which the water is boiling vigorously. A little distance away the steam condenses in the colder air and small particles of liquid water can be seen. This is usually, but incorrectly, called steam. In ordinary everyday speech this does not matter but in Science it is important to say exactly what we mean.

Expt. 13. Fit up an apparatus as in Fig. 4. Put some water in the flask and boil it. What happens to the water in the flask? The water vapour passes through the Liebig condenser where it is cooled by the cold water which flows constantly through the jacket. What happens to the water vapour as it passes through the condenser? The liquid in the small flask is called distilled water. This process is called *distillation*, that is, evaporation followed by condensation.

Expt. 14. Replace the water in the distillation flask by a strong solution of common salt and distil it. Taste the distilled water. It does not taste of salt. Place a few drops on a clean watch-glass and warm gently on a gauze fixed well above a small flame. Is there any deposit on the watch-glass when the water has evaporated? Examine the water in the distillation flask after you have distilled for a long time. Do you see any solid particles? If so, what are they?

The purpose of distillation is to separate a pure liquid from its impurities, for all dissolved solids are left behind when the liquid evaporates. Other liquids besides water may be dis-

tilled, and we shall see later how the method of distillation may be used for separating mixtures of different liquids. Distilled water is needed in the laboratory in large quantities, and there is usually an apparatus kept in the laboratory for producing distilled water cheaply. The principle of it is that of Experiment 13. Distilled water is also produced in large quantities on some ships from sea water. Before it is used for drinking it has to be

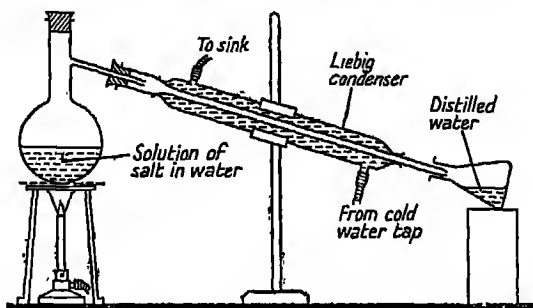


FIG. 4. Distillation using a Liebig condenser.

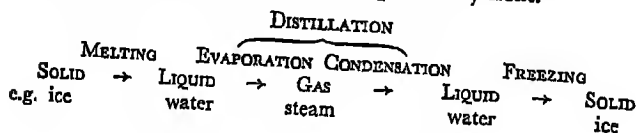
shaken up with air. Freshly distilled water has little or no air dissolved in it and so tastes flat. Some laundries and factories also make distilled water in large quantities (see Chapter XVII).

STATES OF MATTER

We already know that water can exist as ice (a solid), as liquid water, and as steam (a gas, or vapour). Many other substances can exist in these three states. When we are describing a substance, usually the first thing we say is whether it is a solid, liquid, or a gas. We are not often in doubt about the state of a particular substance, but occasionally we have some doubts about substances like pitch and sealing-wax. When you wish to see if a substance is in the solid or liquid state you tilt the vessel containing it. If it flows you say that it is a liquid. Solids do not flow like liquids. Gases also flow. Later you will make gases heavy enough to be poured from one vessel to another. Substances which flow, that is, liquids

and gases, are called *fluids*. If you pour tea into a cup you can stop pouring when the cup is half-full. The tea in the cup will not then fill the cup. But if you put some gas in a vessel the gas will fill the whole space if left long enough. (We shall not go far wrong if for the present we regard a vapour and a gas as the same thing.)

Whether a substance exists naturally as a solid, liquid, or gas is nearly always a matter of temperature. We in England think of water as a liquid. We might think of it as a solid (ice) if we lived in the coldest part of the world. Wax, butter, and fats may be solids on a cold day but liquids on a hot day. Some solids, however, cannot be liquefied by heat.



NATURAL DISTILLATION

Water from seas, lakes, rivers, and the damp surface of the earth is constantly being evaporated by the heat of the sun, and exists for a time as water vapour in the atmosphere. Under cooler conditions the water vapour is condensed and forms clouds which consist of numerous particles of liquid water mixed with air. The particles forming the clouds are able to float for a time as the air below them is usually rising. Rain falls when the particles increase to such a size that the rising current of air can no longer support them (Ch. XXX). If it is very cold when the condensation takes place snow is formed.

Rain water contains very little dissolved matter, no more than is dissolved from the atmosphere as the rain passes through it. The purity of rain water depends on the kind of air through which it has passed. That falling over towns is naturally less pure than that falling through the clearer atmosphere of the countryside. Rain-water always contains in solution gases which it has dissolved from the air, and in addition, a very little solid matter dissolved from the dust of the atmosphere.

RAINFALL

The amount of rain falling in a district is of great importance. On it depends to a large extent the kind and amount of vegetation possible, and ultimately the whole life of the district is affected.

Rainfall is measured in inches. The rainfall at Edinburgh in the year 1937 was 26 inches. This means that if all the rain which fell at Edinburgh during that year had remained there on level ground, none sinking in, and none being lost by evaporation, then at the end of the year the water would have been 26 inches deep.

Rainfall is measured by a rain gauge (Fig. 5). Try to make

one for yourself. The rain is caught in a funnel and runs immediately into a bottle so that there will be no loss of water by evaporation. The gauge must be so placed that no splashes from the ground enter the funnel and care must be taken that it is not blown over. It should be fitted with a heavy base to prevent this, or should be sunk vertically in the ground so that it projects about 3 inches above the surface. This prevents any water entering the gauge from the surface of the ground.

Every morning at the same time the water (if any) in the bottle should be poured into a measuring cylinder. This is graduated with reference to the area of the funnel opening, so that the rainfall may be read in inches.

The readings from the gauge might be tabulated thus:

January 19 . Place.....

Date	1	2	3	4	5	6	7	8	9	&c.
Rainfall in inches										

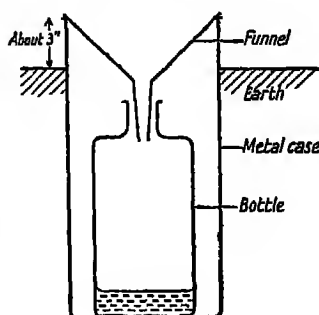


FIG. 5. A rain gauge.

A graph of the readings should also be made. Fig. 6 shows a graph of the rainfall at London for 1937.

Maps showing the rainfall in all countries during summer and winter are now to be found in all good atlases. They are important in the study of Geography, because the activities of

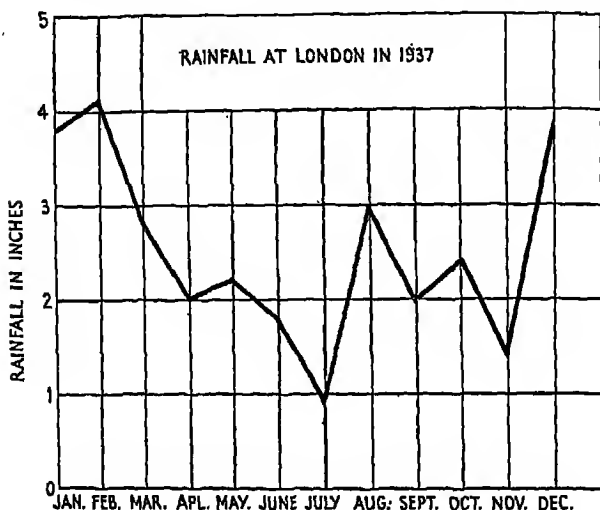


FIG. 6.

Man are so much bound up with the rainfall of the district in which he lives.

The wettest spot on the earth is Cherrapunji, in Assam in North-East India. It has an annual rainfall of over 400 in. Tea and rice are cultivated there. Compare this rainfall with that of London and New York. In 1937 the annual rainfall of London was 30.2 inches, and of New York 48.4 inches.

NATURAL WATERS

Of the rain that falls on the earth some is immediately evaporated and some sinks into the soil. Some of this is used by plants and animals. Some sinks very deep down into the earth, but eventually most of the water which falls as rain is

changed into water vapour and subsequently falls again as rain. There is a circulation of water from liquid to vapour and then to the liquid state again. Some water, especially that which sinks very deeply, remains in the liquid state a long time. As water passes through the various rocks it dissolves many substances. We usually think of river water as fresh compared with that of the sea which is salt. But river water contains dissolved substances and other insoluble substances in suspension. These it carries to the sea. Much of the suspended matter is deposited at the mouth of the river while the dissolved substances enter the sea. This partly accounts for the sea's saltiness as the water is continually evaporating leaving the dissolved solids behind. Inland lakes with no outlet to the sea are often salt lakes. The waters of wells and springs contain dissolved material because the water has passed through various kinds of rocks before reaching the wells or springs. Some well and spring waters contain much dissolved matter, some little, according to the nature of the rocks through which they have travelled. Pure spring water has hardly any taste. The 'sparkle' is due to dissolved gases (air and carbon dioxide). Geysers are hot springs.

The effect of these dissolved substances on the water will be studied later. Water which has drained through soil naturally contains dissolved matter and this is so important from our point of view that it must be studied in detail.

WATER SUPPLY

People live together in large towns and it is important that they should have a plentiful supply of good water for drinking, cooking, cleansing, and manufacturing purposes. This is a serious problem in large cities like London, Manchester, Liverpool, and Glasgow where the local supply is not sufficient. Water has often to be brought long distances. Manchester brings much of its water from Thirlmere and Hawes Water in the Lake District, about 100 miles away. Much of the water used in Liverpool is brought 68 miles from Lake Vyrnwy in Wales. Glasgow obtains its water from Loch Katrine, 26 miles away. London obtains water from the Thames and from wells.

The river Vyrnwy is a tributary of the Severn. A large dam was built across the mouth of a large flat valley through which the river Vyrnwy flowed. This kept all the water in the valley, thus forming a large reservoir, a lake $4\frac{3}{4}$ miles long, with a surface area of 1,100 acres and a maximum depth of 84 feet. The lake contains 13,000 million gallons of water, supplied by

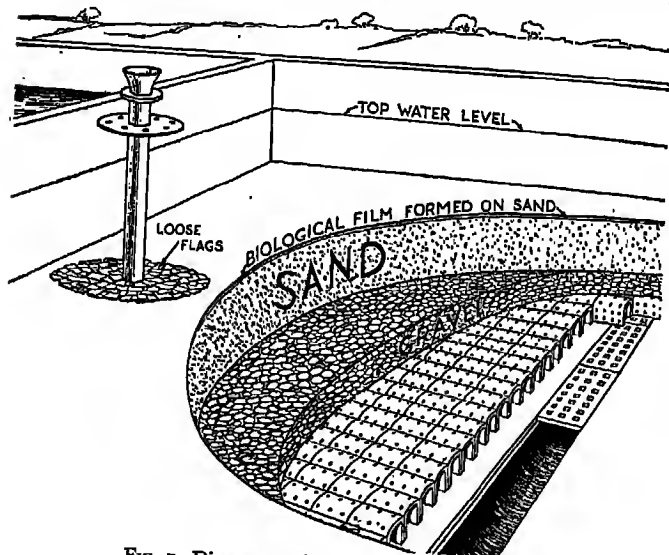


FIG. 7. Diagrammatic section of a filter bed.

streams flowing into it from the surrounding hills. The water from 18,000 acres of land flows naturally into the lake. This area is called the *gathering ground* or catchment area. The water for the supply of Liverpool is drawn off near the surface, passes through copper gauze strainers, and then along pipes, at least 7 feet in diameter, to the filter beds at Oswestry, a distance of about 20 miles.

Filter beds are usually arranged as shown in Fig. 7. The floor of the bed is paved with tiles with spaces between. Above the tiles is a layer of rough gravel one foot thick. Above the gravel

is a layer of fine sand 2 feet 6 inches thick. The depth of water above this is also 2 feet 6 inches. The water from the lake is again passed through copper gauze and then sprayed gently on to the filter bed. By this means the water is exposed to the action of light and air, both excellent agents for destroying microbes which might cause disease. This method of spraying also allows the water to fall gently on the surface of the water in the filter bed and thus the top layer of sand is not disturbed.

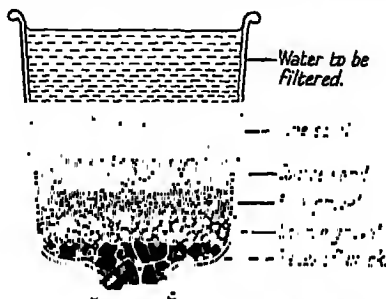


FIG. 8. An inverted bell-jar used as a filter.

This is important as it is found that the top layer is very effective in clearing the water of microbes. The water trickles through the filters and is then conveyed to reservoirs where it is stored.

Expt. 15. To make a filter bed. Obtain a large bell-jar or other suitable vessel (Fig. 8). Remove the stopper, invert the jar, and place at the bottom some pieces of clean brick. Then in the following order put in layers of coarse gravel, fine gravel, coarse sand, and lastly a thicker layer of fine sand. You should now have about two-thirds of the bell-jar full. Put some thick paper loosely on the top of the sand and pour dirty water on to the paper. In this way the water will reach the sand without disturbing it too much. When the bell-jar is almost full of water remove the paper. Note how long it takes for the water to trickle through the filter and come out at the bottom. Compare the appearance of the water which trickles out with that of the muddy water put into the filter.

The water collected and stored in a mountainous district flows through the pipes naturally to the towns in the valleys at

a lower level. Sometimes during the journey it is necessary to pump the water to a higher level so that it will then flow better to the required place. In distributing the water to the houses and factories in the town the water is first stored in reservoirs which are higher than the highest point to which the water has to be served. If necessary the water is pumped to the height of these reservoirs.

Some towns obtain their water from wells, the water of which is pumped to a high point and then allowed to flow through pipes to the houses, or it is pumped directly into the mains.

QUESTIONS

1. State clearly, giving examples, the difference between a suspension and a solution.

How may (1) a soluble substance be recovered from a solution and (2) the solid and liquid parts of a suspension be separated?

2. Describe how you would separate a mixture of salt and sand in order to obtain them in a dry condition.

3. What is a saturated solution?

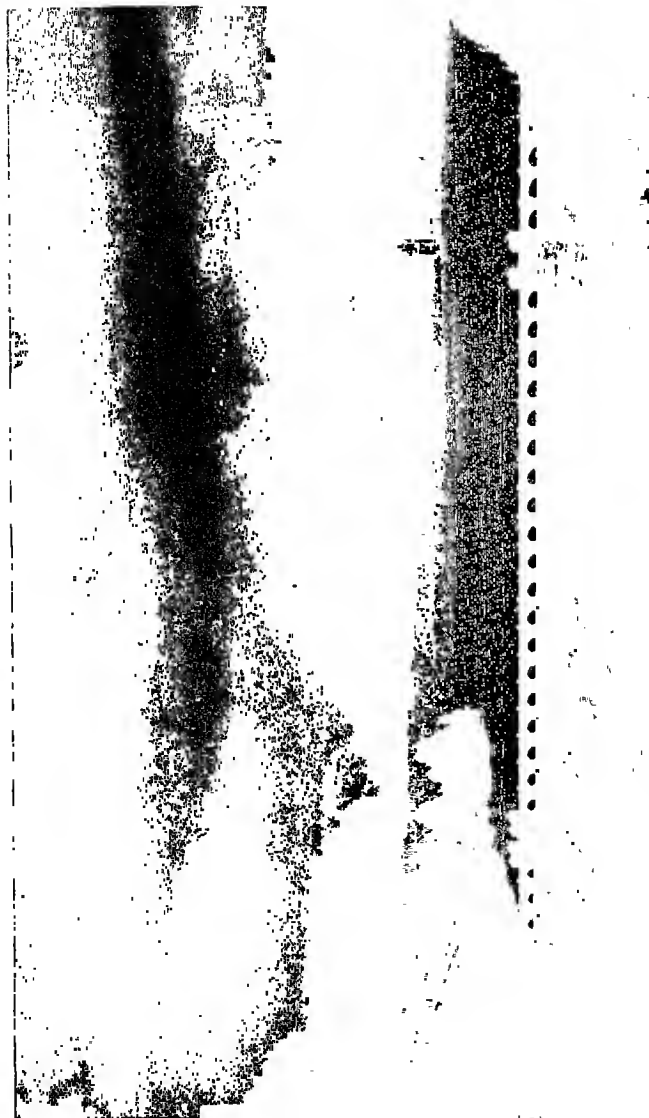
You are given some commercial copper sulphate. Describe how (a) you would purify it by crystallization, (b) you would obtain a large well shaped crystal of copper sulphate.

4. What is distillation? What is it used for? Give two examples to illustrate your answer. How would you obtain some distilled water without using any apparatus except ordinary kitchen utensils?

5. What dissolved matter (if any) does rain-water contain? How is rainfall measured? Describe the construction and use of a rain gauge. Which is the wettest region (a) on the earth, (b) in England?

6. How do the following natural waters differ as regards (a) matter in solution, (b) matter in suspension: rain-water, river water, deep well water, sea water?

7. Why is it essential that people living in large towns should have a plentiful supply of good water? Describe the water supply of any large town you know.



I. Lake Vyrnwy, showing the dam and straining tower

III

SOME PLANT RELATIONS TO WATER

It is common knowledge that plants cannot live long without water. All kinds of questions come to our minds. Why cannot plants live without water? How does the plant obtain its water? What does it do with it after obtaining it? How much of a living plant is water? Let us try to find answers to some of these questions by experiment.

WHAT PROPORTION OF A LIVING PLANT IS WATER?

Expt. 16. Strip some fresh leaves from a plant and weigh them. Leave them in a clean warm dry place for several days until they are dry and shrivelled. Weigh again. Note the loss in weight and express this as a percentage of the original weight. Do the same with other plants and different parts of plants, e.g. a piece of potato, a piece of apple, a green stem, a woody part of a plant, a piece of root, &c. What do you find?

Your results will not be quite accurate because under such conditions all the water will not be lost. Your percentage will be too low. A more accurate method would be to heat the weighed leaves in a steam oven until the weight is constant, i.e. until two consecutive weighings are the same.

A large percentage of all plants is water. Some plants, e.g. the green scum often found floating on the surface of ponds, have a higher percentage of water than others. The different parts of plants differ in the percentage of water they contain. Fresh lettuce leaves contain 94 per cent. The woody parts of a plant contain about 50 per cent., fruits about 90 per cent., and the fleshy parts of some plants as much as 95 per cent. Rabbits can be kept alive without drinking water if supplied with sufficient lettuce leaves to eat.

DOES WATER ESCAPE FROM A LIVING PLANT?

Expt. 17. Take two test-tubes each three-quarters full of water. In one insert a leafy shoot and in the other insert a similar shoot from the same plant except that it must be stripped of most of its leaves.

Into each test-tube pour a little olive oil. This remains as a layer on the surface and prevents loss of water by evaporation. Weigh each of these test-tubes with their contents separately and then suspend them near to each other (Fig. 9). Leave for a day. Re-weigh each separately.

Both lose weight. This can only be loss of water through the plant. The leafy shoot loses more water than does the other shoot.

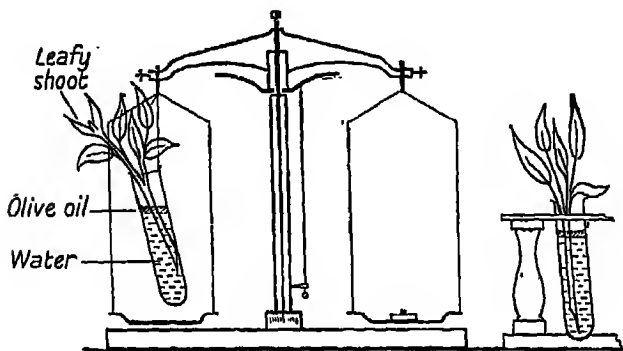


FIG. 9.

HOW DOES THE WATER ESCAPE FROM THE LIVING PLANT?

Expt. 18. Choose four fresh laurel leaves with short stalks from the same plant. Let them be approximately the same size. Vaseline the ends of the stalks, and also cover the upper surface of the first, the lower surface of the second, and both surfaces of the third with vaseline. Leave the fourth untouched. Hang the leaves up in a warm room and leave them there for a few days. Notice which leaf becomes limp before the others.

The fourth leaf wilts first, the first a little later, the second takes much longer, and the third does not appear to wilt at all.

A more accurate method would be to weigh the leaves in each case at the beginning and the end of the experiment. The loss in weight would indicate the amount of water lost.

Expt. 19. Dry a lilac or privet leaf thoroughly between pieces of blotting-paper and place it between two pieces of blue cobalt chloride paper. Cover each side with a strip of dry glass and clip them

together to prevent the entrance of water. The blue cobalt paper gradually turns pink. This is due to moisture given off by the leaf. The change occurs more rapidly on the under surface of the leaf. Why is this? To answer this question we must examine a leaf in some detail.

EXAMINATION OF A LEAF

Examine as many different kinds of leaves as you can.

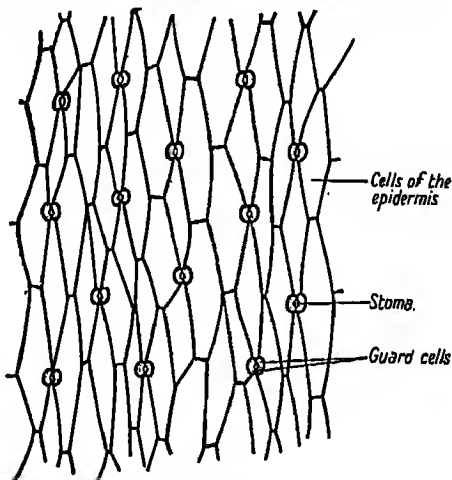


FIG. 10. A portion of the epidermis of the leaf of an iris (see p. 20).

There is an enormous variety. Many plants can be identified by their leaves alone. You will find that most of the leaves you examine consist of two parts, a broad flat portion, the *blade*, and a leaf-stalk. The latter is usually continued in the flat part as a vein. The veins often form a network, but each vein, even the smallest, can be traced back to the point where the leaf stalk enters the blade. In some leaves, e.g. those of the daffodil, iris, lily, and all grasses, there is no net-work of veins. The veins in these leaves all run parallel. When we come to understand the work the leaf has to do we shall understand the importance of the form of the leaf.

If an iris leaf is bent sharply until it is broken, the two parts may be pulled away from each other in such a way that the 'skin' of the under surface of the leaf is stripped off. Try to do this and mount a portion of the 'skin' in glycerine and examine under the microscope, first under the low power and then with the high power. Fig. 10 shows what it is possible to see when such a specimen, suitably stained and mounted, is examined under the high power. The leaf seems to be divided into a large number of very small parts. Each part is called a *cell*. We shall not get very far in our attempt to understand living things until we learn something about cells.

THE APPEARANCE OF LIVING MATTER UNDER THE MICROSCOPE

Nearly all living things, plants and animals, have a cellular structure. This is seen much more clearly in plants than in animals because the cell walls of plants are much more distinct than those of animals. Most animal cells have no cell walls. Some living things are so small that they consist of only a few cells, and some consist of only one cell. The latter are said to be *unicellular*, or, as some prefer to call them, *non-cellular*. In ordinary living things, however, the number of cells is enormous. They are of many shapes and sizes, but all living cells contain a substance called *protoplasm*. It is impossible to say what this living substance is. It looks like an almost colourless and transparent but granular jelly. When the protoplasm of a cell is carefully examined, a denser portion, called the *nucleus* is seen. It is not often easy to see this in the cell unless the protoplasm has first been suitably stained. A little weak iodine solution will turn protoplasm brown, and the nucleus a deeper brown. It kills the protoplasm in the process.

There are many other substances and bodies in a cell, including much water.

STOMATA AND GUARD CELLS

In your examination of the skin of the iris leaf note: (1) the elongated cells forming the greater part of the skin, (2) among these cells at fairly regular intervals, pairs of cells of quite

different shape enclosing a tiny hole or pore. This pore is called a *stoma* (plural *stomata*) and the cells enclosing it are called *guard cells*. When looking through a microscope it is difficult to remember that we are viewing cells which have three dimensions, length, depth, and breadth. The cells look

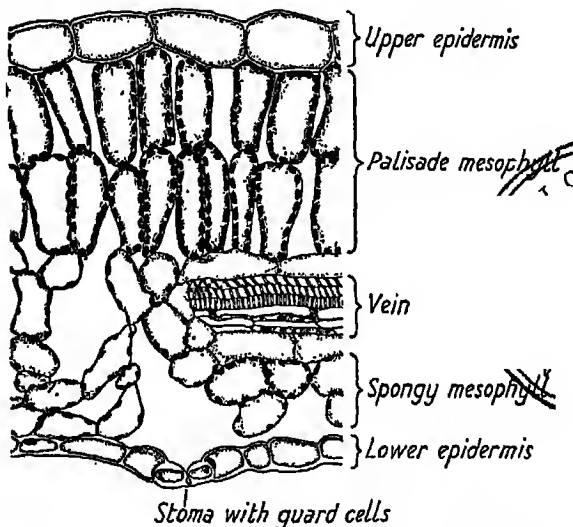


FIG. 11. A small portion of the cross-section of a typical green leaf, as seen under the microscope. (Highly magnified.)

flat and we have constantly to remind ourselves that they have depth as well as length and breadth. We cannot tell what guard cells are like until we have seen them from another direction. Examine a prepared slide of a transverse section of a leaf (Fig. 11). We are now looking at the thickness of the leaf. Note: (1) the row of cells forming the 'skin' (*epidermis*), the outer wall thickened; (2) the closely packed row of cells under the epidermis, containing many small green bodies, *chloroplasts*; (3) the mass of loosely packed cells with large spaces between; (4) the lower epidermis, like the upper except

that the outer walls are not thickened and occasional guard cells are seen. The guard cells are the only cells of the epidermis which contain chloroplasts. The stoma is a pore through

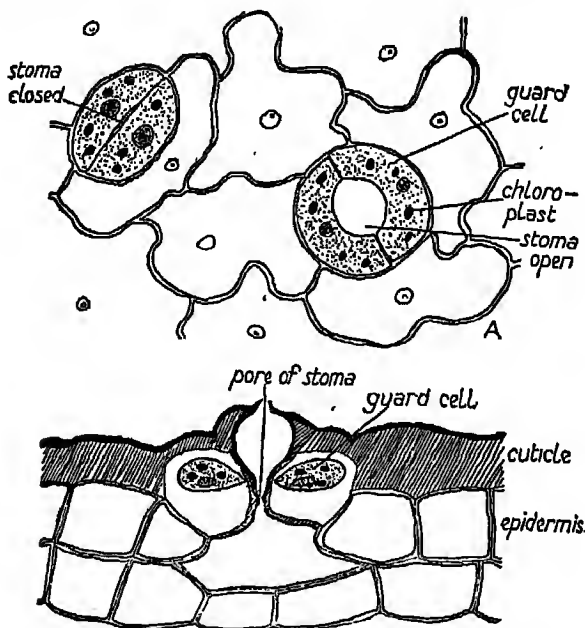


FIG. 12. A. Portion of a leaf epidermis with stomata in surface view.
B. Section of epidermis and stomata. (Both highly magnified.)

which air can enter, or air and water vapour can pass from the inside of the leaf to the external atmosphere. It is through the stomata that the plant loses its water in the form of water vapour. In most plants the stomata are in the lower epidermis and very few in the upper epidermis. Now re-read page 18 and you will understand the results of Experiments 18 and 19.

The stomata open and close under the action of the guard cells. When the latter become distended with water, they bend away from the stoma, which becomes larger. On losing water

the guard cells become less curved and the stoma closes (Fig. 12). It is commonly stated that the guard cells are influenced by the amount of water in the atmosphere, that is, they cause the stomata to open on damp days and to close on hot dry days, so as to conserve the moisture. This is not so. The stomata open and close under the influence of light.

Water does not normally escape from the plant through the epidermis of the leaf, because the thickening of the external wall makes this almost impervious to water.

HOW DOES THE PLANT OBTAIN WATER?

Expt. 20. Obtain a healthy plant such as a geranium which has been growing well in an ordinary plant pot. Stand it in water for an hour until the soil is soaked with water. Take it out and allow it to drain until no more water drips from the hole in the bottom of the pot. Dry the pot on the outside with a duster and make it impervious to water by greasing the sides and bottom of the pot liberally. The hole must be sealed and the sealing material greased. Cover the top of the pot with a well-fitting circle of cardboard, leaving a hole for the stem of the plant. Grease the cardboard well, especially round the edges and where the cardboard touches the stem. Put the plant in a good growing position inside a room. Leave it until it begins to wilt. This will probably take some weeks. Take the cardboard off and examine the soil and roots.

The soil is dry. Where has the water gone? It could not have left the pot other than through the plant because all other possible routes have been blocked.

An alternative method of performing the experiment would be to fasten rubber sheeting round and over the top of the pot, sealing off with adhesive tape. The pot and contents should be weighed, left for a day, and weighed again. Loss of weight would indicate that the plant had lost water.

AT WHAT RATE DOES THE PLANT TAKE IN WATER?

The intake of water by a plant can be very conveniently studied by using the instrument illustrated in Fig. 13. It is called a potometer, and is used as follows:

The screw-clip *A* is opened and an india-rubber tube with screw-clip is fitted to the end *B* of the graduated capillary tube.

Water is poured into the thistle funnel. It fills the apparatus except for a portion of the capillary tube. A leafy shoot is fitted for a portion of rubber tubing to *C*. Clip *A* is now opened, clip *B* removed, and the water flows along the capillary tube to the end. Clip *A* is now closed. As water is taken by the plant, the end of the column of water in the capillary tube

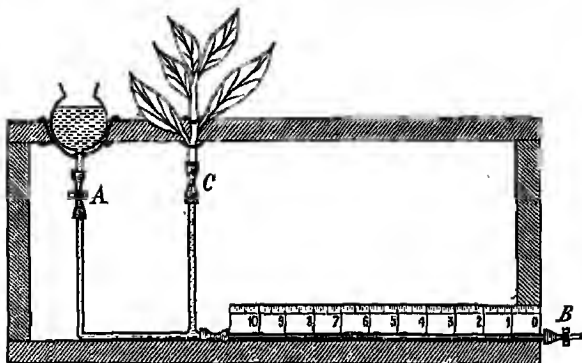


FIG. 13. A potometer.

moves. The rate at which the plant takes in water can thus be estimated.

Expt. 21. Use the potometer to compare the rates at which water is taken in by a leafy shoot under the following conditions: in a cold room, and in a hot room; on a wet day and on a dry day; during darkness, and during a period of sunshine; in a still atmosphere, and in a current of air.

As the time taken for these experiments is comparatively short, it is unlikely that any of the water taken in is used for growth. The amount of growth of the plant will be so small that it can be neglected. Thus we may assume that all the water taken in by the plant was given out, and that when we measure the intake of water by this method we are also measuring the rate of loss of water by the plant. The loss of water by a plant by this method is called *transpiration*.

The external conditions affecting transpiration are thus seen to be the same as those governing evaporation. High

temperatures, dry air, and winds increase transpiration, whilst low temperatures, moist and still air decrease it. Again, since the water vapour is given off mainly through the stomata, the amount of water lost by a plant will depend largely on the number and size of its leaves and the number of stomata they contain. The rate of transpiration is also affected by the amount of sunlight, for the guard cells open and close under the influence of light.

HOW DOES THE WATER ENTER THE PLANT?

The experiments we have performed and our every-day experience direct us to examine the roots of the plant for an answer to this question. When a gardener transplants seedlings he waters them well, because he knows that he must have disturbed the roots when he lifted the plants, and that for a time the plants will have difficulty in obtaining all the water they require. He therefore does his best to help them. In spite of his care the newly transplanted seedlings often wilt, showing that they are unable to obtain the water he has supplied.

Expt. 22. Sprinkle some mustard or cress seeds on some muslin stretched over the mouth of a jar full of water. Let a few strands of the muslin hang in the water so that the muslin on which the seeds lie will always be wet. Place the jar in a warm place. The seeds will soon germinate and the roots will go through the muslin towards the water. When the roots are over an inch long take the seedlings out and examine them. Not far behind the root tip you will find numerous very fine root hairs (Fig. 14). Place a seedling on a slide in water and examine it under the low power of the microscope. Try to see how a root hair is attached to the root.

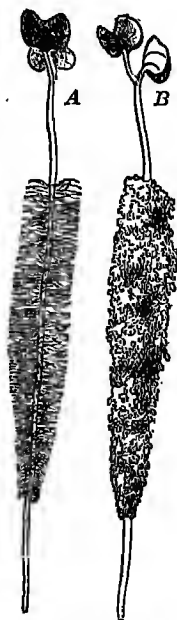


FIG. 14. Mustard Seedlings, showing (A) root hairs; (B) soil clinging to root hairs

A root hair is a tubular outgrowth from a single cell in the outside layer of cells of the root. It is very long. If some iodine

is put into the water on the slide you will see the protoplasm as a layer round the inside of the cell wall. You may be able to see the nucleus in the protoplasm. The greater part of the cell appears to be empty, but is in fact filled with a clear liquid. Such spaces are called *vacuoles*. It is not pure water that fills

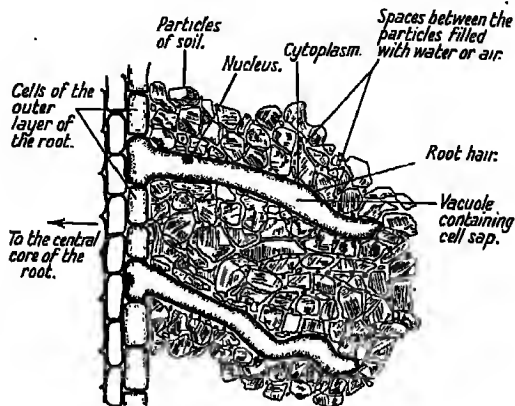


FIG. 15. Root hairs in intimate contact with the soil.

the vacuole in a root hair, but a watery solution of substances. This liquid is called the *cell sap*.

Grow some mustard seeds, this time in very fine soil. Pull up the seedlings and note how the soil clings to the region of the root hairs. Figs. 14, 15 illustrate the intimate contact between the root hairs and the particles of soil. The water needed by a plant is taken in by the root hairs. It is not yet fully understood how this is done, but we can learn something about the method.

OSMOSIS

Expt. 23. Put some undamaged raisins in water, and leave them there for a few days. They swell and become plump. Water passes in through the skin.

Expt. 24. Peel a large potato and cut one end so that it will stand up (Fig. 16). Scoop out the middle, leaving thick walls. Pour a little sugar solution into the cavity thus made and stand the potato in

water. The level of the water outside the potato should not reach the level of the bottom of the hole in the potato. Leave for some time and note the level of the solution in the potato. It rises. Water from outside the potato must have passed through the cells of the potato and thus increased the volume of the solution in the hole. The solution of sugar is now weaker.

Expt. 25. Repeat the above experiment, but boil the potato for a few minutes after shaping. The level of the solution in this case does not rise.

Expt. 26. Fasten some soaked parchment paper (or a piece of pig's or sheep's bladder, or a piece of thin cellophane) to the wide end of a thistle funnel by means of several turns of waxed thread. Test the joint to see that it is water-tight; if it is not make it so, otherwise the experiment will fail. Fit up the apparatus as in Fig. 17. Pour some sugar solution coloured with red ink into the thistle funnel and tube, and mark the height of the liquid. Lower the thistle funnel into a beaker containing water. Watch the movements of the column of sugar solution for several days. The level of the solution rises. Water must have passed through the parchment paper into the sugar solution thus increasing its volume and making it weaker.

Water passes through the parchment paper (which is called a membrane) as if it were being pushed from outside or pulled from inside. It is not yet known what is the real cause of

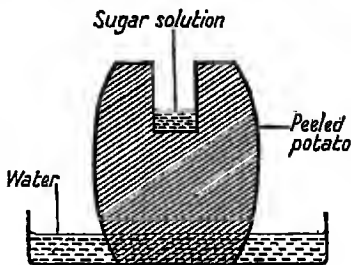


FIG. 16.

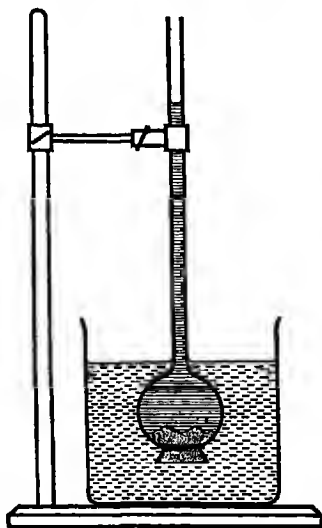


FIG. 17. Osmosis. A thistle funnel containing sugar solution; and a jar of water.

the behaviour but it is certain that the water travels through the membrane to the solution, thus diluting it. This behaviour is called *osmosis*, and the action gives rise to a pressure on the solution side called the *osmotic pressure* of the solution.

In Experiment 23 the skin of the raisin acted as the membrane. Inside this was a strong solution of sugar. Outside was water. The water passed from the outside, through the membrane to the inside, thus causing the raisins to become plump but diluting the sugar solution. In osmosis the water always passes in that direction which causes the stronger solution to be diluted.

In Experiment 24 the cells of the unboiled potato acted as membranes through which the water passed to the solution in the hole in the middle of the potato. This shows that water can pass by osmosis through many membranes in succession. In the boiled potato no osmosis occurred. Boiling has the effect of killing the cells, so it would appear that the membrane is not the cell wall but something in the living cell.

THE PART TAKEN BY OSMOSIS IN THE ENTRY OF WATER INTO A PLANT

The root hairs are in very close contact with the soil and soil water. Soil water is a very weak solution of many substances in water. The large vacuole of the root hair contains cell sap, which is also a weak solution of many substances in water. Of these two solutions the cell sap is the stronger. Osmosis takes place, the water passing from the soil into the cell. It must not be assumed that the cell wall of the root hair corresponds to the membrane in our osmosis experiment. It is probable that the protoplasmic lining is the membrane. The problem has not yet been solved, but our experiment with the potato suggests that it is some living part of the cell which forms the membrane.

Some gardeners water their plants with solutions of substances which they know from experience will help their plants to grow. They are careful, however, to keep these solutions weak, otherwise the cell sap would be weaker than the soil water, and osmosis would either not take place at all, or would be in the wrong direction. Thus the plant would not obtain

water; it might even lose water to the soil. This, of course, would kill the plant in time.

DIFFUSION IN LIQUIDS

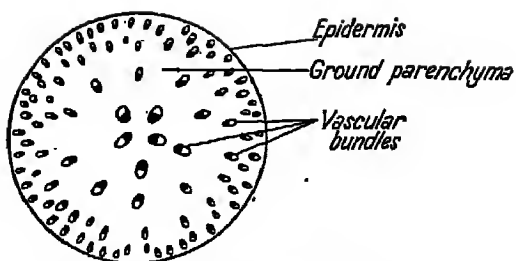
Expt. 27. Place a crystal of copper sulphate (or potassium permanganate or any other highly coloured solid which is soluble in water) in a beaker of water and leave it for a time undisturbed. Note what happens from day to day.

The copper sulphate slowly dissolves in the water, and around the crystal there is a solution of copper sulphate in water; but a short distance from the crystal there is no dissolved copper sulphate since the water is colourless. After a time the colour of the water some distance from the crystal indicates that the copper sulphate in solution is spreading. In a few days the whole of the water in the beaker shows by its colour that it contains dissolved copper sulphate. We say that the copper sulphate in solution has diffused through the liquid. This is an example of the *diffusion* of a dissolved solid in a liquid.

Consider again the result of Experiment 26, where we had a sugar solution coloured with red ink separated from water by a membrane. We noticed that the water passed from outside through the membrane to the sugar solution. If we had kept our experiment going long enough, we should have noticed that in time the water outside was stained with red ink. Some of the sugar in solution had passed through the membrane to the water outside. Substances in solution will pass through some membranes by diffusion. A membrane which will allow water to pass through it by osmosis, but which prevents the passage of all dissolved substances by diffusion, is called a *semi-permeable membrane*. The membrane we employed in our experiment was not semi-permeable, for it allowed the slow passage of sugar in solution through it.

Most animal and plant cells are like this. All substances entering the cells do so in solution. They could not do so if the protoplasm acted as a semi-permeable membrane. They enter the cell because the protoplasm is never perfectly semi-permeable. It will allow some substances to enter and not others; in other words it is selective. We have seen that the membrane is

(30)



18. Transverse section of a stem of monocotyledon.

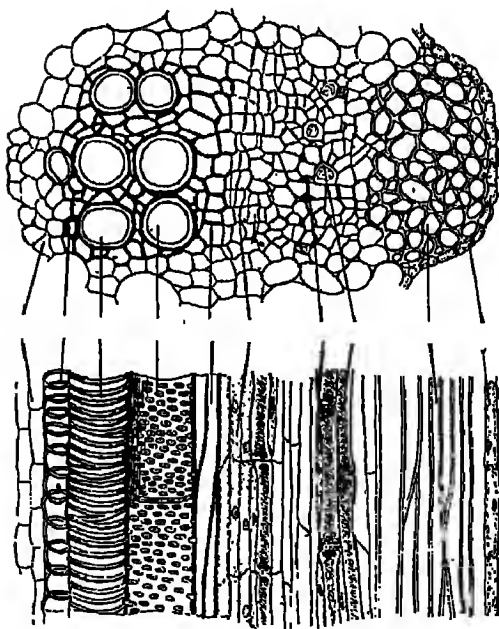


FIG. 19. Transverse and longitudinal sections of a single bundle of a sunflower.

probably the protoplasmic lining of the cell, not the cell wall. The latter is permeable. Dead cells will not absorb water by osmosis because the membrane has been destroyed.

It is of the utmost importance to plants and animals that they should be able to obtain not only water but also dissolved substances. The root hairs of plants obtain their water by osmosis, and in addition they obtain some dissolved substances from the soil water, by diffusion.

HOW DOES THE WATER TRAVEL IN THE PLANT?

We have considered how water enters the root hairs, but what happens to it then? How does it reach the leaves of a tall tree? The full explanation is not known and much of that which is known is too complicated to give here. Water passes from the root hairs to the adjacent cells and this goes on from cell to cell in all directions again by osmosis. This cannot completely account for the rise of water from the roots to the top of a large plant, however, so we must look for some other explanation.

Expt. 28. Cut under water a leafy stem of deadnettle, and place the cut end in a weak solution of red ink (or eosin). Do the same with a sprig of an apple tree, a 'stick' of celery (a very long leaf-stalk) (p. 19), and any other plant you choose. Those mentioned are known to give good results. Examine them from time to time. What happens? Note particularly the veins of the leaves of the dead nettle. Cut across the stem. Cut through the stem longitudinally. What do you notice? The coloured water has risen in the plant. The water does not rise through the whole width of the plant, but keeps to what appear to be well-defined channels. Take a mounted needle and try to remove one of the 'channels'. You will find this very easy with celery. Break the 'channel' up, keeping the strands as long as possible. Examine the teased portion under the microscope.

These strands are called *bundles*. They form continuous channels from the root to the leaves. They have more than one important function to perform, but for the present we shall confine our attention to their function of carrying water.

THE STRUCTURE OF THE STEM OF A PLANT

Expt. 29. Cut a very thin transverse section of the stem of a plant. (Broad bean, deadnettle, or any plant that is not too woody.) You must use a very sharp knife, scalpel, or razor moistened with water.

Hold the stem firmly in the left hand and cut towards you. It needs practice, but with patience very thin sections can be cut. If the stem is too soft to cut, it may be held between two pieces of potato, carrot, or elder pith. Cut many sections and place the thinnest on a slide in a little water and examine under the microscope. Examine a second section which has been stained with iodine, and a third stained with Schulze solution.

Expt. 30. Do the same as in Experiment 29 but cut the stem longitudinally. This is not as easy as cutting transversely. Examine prepared slides. Repeat these experiments with a tulip or montbretia stem.

Figs. 18 and 19 show what to look for. The bundles are seen in most cases in a ring. In the tulip and montbretia they are distributed about the stem. Note the walls of the cells stained yellow by the Schulze solution. They are made of wood (lignified tissue). It is through the wood cells of the bundles that the water is conveyed. For the most part they have no protoplasm and are dead. Note the longitudinal sections. You see how long these cells are. In fact, they are called *vessels*, and have been made up of many cells, end to end, the transverse cell walls of which have disappeared. Note the thickening of the walls of the vessels. Some have spiral thickening, some have rings round them (*annular vessels*), and some have the thickening in the form of a net-work (*reticulate vessels*). The wood vessels, besides carrying water, act as a kind of skeleton to the plant, helping to support it in an upright position.

THE STRUCTURE OF THE LEAF

You perhaps noted in Experiment 28 that the veins of the leaf became red after the shoot had been standing in coloured water for some time. The veins are a continuation of the vascular bundles of the stem.

Expt. 31. Make transverse sections of the leaf-stalk of a plant and of the leaf. You will not find this easy but you may succeed if you hold the leaf between pieces of elder pith. It is worth trying, for the sections you make yourself are usually more convincing than prepared slides. Examine prepared slides as well for they will show you much that you have missed in your own. Note the bundles in the leaf-stalk. Make sure that you recognize the wood vessels in the leaf and the

leaf-stalk (Fig. 20). If a leaf is left to decay in a little water, sometimes all the soft part of the leaf decays leaving the vascular system intact, commonly called 'skeleton leaves'.

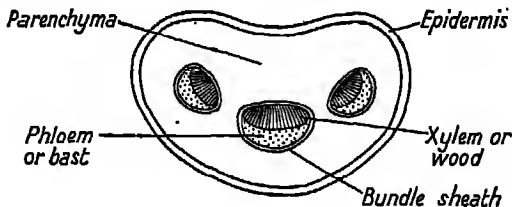


FIG. 20. Transverse section of petiole of leaf.

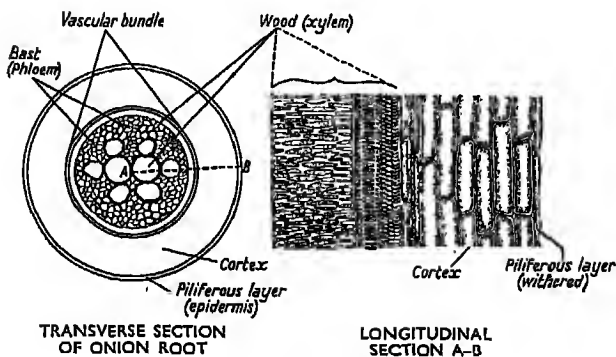


FIG. 21. Onion root.

THE STRUCTURE OF THE ROOT

Expt. 32. Crush the root of a mustard seedling in water on a slide and examine under the microscope. You will see the vascular system in the middle of the root, running from the stem almost to the tip of the root. Make transverse sections of a root, stain with aniline sulphate solution, which stains wood yellow. Examine also prepared slides. The onion root is good for this purpose (Fig. 21).

THE TRANSPIRATION CURRENT

Water from the soil enters the root hairs by osmosis. The water then travels in the root inwards from cell to cell, again by osmosis, until it reaches the vascular system of the root. It travels along this to the vascular system of the stem and so to that of the leaves. Here it leaves the vascular system and enters the spaces between the cells of the spongy tissue where it becomes water vapour (Fig. 11) and leaves the plant by the stomata. This is what happens to most of the water taken in by a plant, but some of it is used by the plant in its chemical processes.

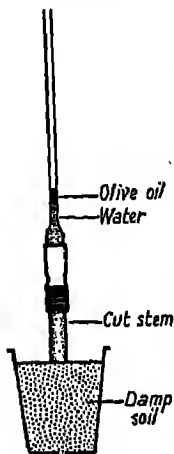


FIG. 22. Root pressure.

We can now attempt to answer the question: 'What causes the water to rise in a plant?' It is partly pulled up by water leaving through the stomata, and water rising to take its place; and it is partly pushed up by a pressure set up in the root. That this pressure exists can easily be demonstrated.

Expt. 33. Cut the stem of a vigorously growing plant and connect the cut end, by means of rubber tubing, to a length of glass tubing supported by a stick pushed into the soil of the pot (Fig. 22). Place a little water in the tube, and on top of this a thin layer of olive oil to prevent loss of water by evaporation. Note the rise of water in the tube, and see if there is any difference when the plant is under warm and cold conditions.

This *root pressure*, as it is called, is due in part to osmotic pressure, but it is difficult to believe that this accounts for the whole of the pressure. It has never yet been satisfactorily explained how water is able to rise to the top of a very high tree.

WHY DOES A PLANT NEED WATER?

1. The protoplasm of a plant consists largely of water, and with the growth of the plant there is, of course, an increase in the amount of protoplasm. Therefore a plant needs water for

growth, which can be rapid only if there is a plentiful supply of water.

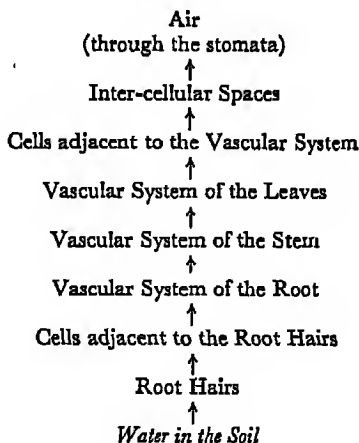
2. The protoplasm is continually being broken down and built up again. This seems to be a part of the process of living. When this breaking-down and building-up stops, then life ceases. A plant needs water for the renewal of protoplasm.

3. Many complex chemical processes are associated with the living cell, and water enters into many of these.

4. A living cell is normally turgid with water, i.e. it is tight, and there is a pressure outwards on the cell wall. This turgidity is sometimes lost in the ordinary life processes of the cell, but if it cannot be maintained when necessary, the cell suffers and eventually dies. This applies to the plant as a whole. This loss of turgidity is the cause of the wilting of a leaf when the plant cannot obtain sufficient water for any reason. A plant needs water to maintain turgidity.

5. A plant needs water for the transport of dissolved substances in the plant.

THE PATH TAKEN BY SOME OF THE WATER FROM THE SOIL TO THE AIR



QUESTIONS

1. How does a living plant lose water? Describe experiments to illustrate your answer. Labelled sketches of the parts of the plant concerned should be given.

2. Describe experiments to show that a land plant obtains its water from the soil.

3. Draw a labelled diagram of a root hair attached to a root. On what part of a root do root hairs occur? Name the processes by which (a) water enters a root hair, (b) dissolved salts enter a root hair.

4. Draw a labelled diagram of a transverse section of the stem of any plant. Indicate the vessels along which the water passes up the stem.

5. Draw a labelled diagram of a transverse section of a leaf. Indicate the method of escape of water from the leaf. In certain leaves there are differences between the upper and lower epidermis of a leaf. What are these differences?

6. Draw a labelled diagram of the lower epidermis of a leaf as seen under the low power of a microscope. What is a stoma? How is its size controlled?

7. What forces are there tending to cause water to rise in the stem of a plant? Describe an experiment to illustrate root pressure.

8. State five reasons why a plant needs water.

9. What do you understand by the terms: osmosis, impermeable membrane, permeable membrane, semi-permeable membrane?

Describe the part played by osmosis in the entry of water into a plant. Why are gardeners advised not to give their plants too strong a dressing of artificial fertilizers?

A. How does water get from the soil into the leaves of a plant? How is the excess of water removed from the leaves and the removal controlled? Describe the various ways in which water is utilized by the plant.

[N.J.B.]

IV

PRELIMINARY STUDY OF THE ATMOSPHERE

We know that we cannot live without air and you have probably realized that all land animals need air. Some of you may know that plants also are dependent on the air, and that they would die if deprived of it for long. People who have greenhouses are careful to see that their plants receive sufficient air. Why do plants and animals, including ourselves, need air? We must learn something about the air before we can attempt to answer this question.

PRESSURE OF THE AIR

We cannot see the air, and on a calm day we are usually unconscious of its existence. On a windy day we feel the pressure against our bodies. Is it a material substance? Has it weight? Does it occupy space? If there is some air in a bottle, we usually say that the bottle is empty; but can we put something else in the bottle without removing the air which is already in? If we wave a large piece of card-board about, we feel the air offering resistance to our efforts. All this, however, is rather vague, and we are not likely to obtain clear ideas, and knowledge of the facts, unless we make some experiments and so find answers to our questions.

Expt. 34. Put an 'empty' bottle, neck upwards, very quickly in water. Note the bubbles rising. What are they? What flows into the bottle as the air leaves it?

Expt. 35. Hold a wide-mouthed jar mouth downwards vertically over a deep trough of water. Slowly lower the jar into the water keeping the jar vertical. What do you notice about the water? Push the jar down until it is all under water. How much water has entered the jar? Why is the jar not full of water? Why has some water entered the jar?

From these two experiments we learn that air is a substance which occupies space, and that water cannot occupy the same space as the air at the same time. The air must come out of the

bottle before the water can enter. It seems also, from Experiment 35, that air can be made to occupy less space than it does normally.

Expt. 36. To show that air has weight. Fit a round-bottomed flask with a rubber stopper through which passes a piece of glass tubing (Fig. 23). To the end of the glass tube fix a piece of rubber

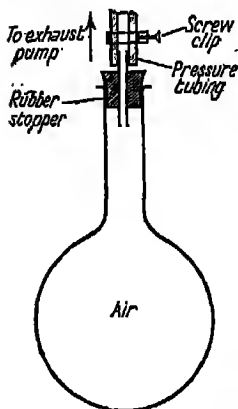


FIG. 23.

pressure tubing with a screw clip. With the clip open, attach the pressure tubing to an exhaust pump, and draw as much air as possible from the flask. Close the clip and detach the apparatus from the pump. Weigh the flask which now contains very little air. Open the clip, thus allowing air to enter the flask. Note the increase in weight. This is due to the air which entered the flask when the clip was opened.

Plan a modification of this experiment by which you would be able to find approximately the weight of a known volume of air.

Expt. 37. Obtain a 'sucker'. This is a round piece of leather which has been well soaked in water, with a tiny hole made in the centre through which a piece of string has been drawn. A knot prevents the string from being drawn right through. Press the

'sucker' on to a smooth surface and pull the string, gently at first, but with increasing strength.

Why does the 'sucker' offer resistance to your efforts to pull it off? It is not the leather, nor the water, nor the smooth surface that is causing it to stick. None of these substances has the property of glue. It must be something else.

The air is pressing on the upper surface of the leather and there is no air pressing on the under surface because there is none there to press. There is a good contact between the smooth surface and the wet leather. If for any reason the air gets under, the 'sucker' can easily be pulled off, because the air underneath is pressing up just as the air on top is pressing down. The two pressures balance, and it is just as if there were no pressure.

He would be a clever person who, knowing nothing of air

pressure, could arrive at this explanation. We must be careful in these experiments not to deceive ourselves into thinking that we have proved the existence of air pressure. If we had not known something of air pressure from our ordinary experience, we should probably have thought of all sorts of things and never of air pressure. Look upon these experiments, not as proving

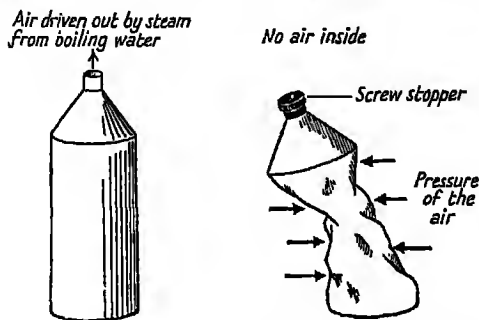


FIG. 24. To show the effect of the pressure of air.

beyond doubt the existence of air pressure, but as illustrating the fact of air pressure.

We can buy things like cigarette ash trays which stick to the glass wind-screen of a car by air pressure. They are 'suckers', but are usually made of rubber so shaped that a good contact is made with the smooth glass surface without the aid of water.

Expt. 38. Obtain a cylindrical tin can, preferably with a screw stopper. Put in a little water, and, with the stopper off, heat the water until it boils vigorously. The escaping steam forces all the air out of the can. Remove the can from the flame, and, while the steam is coming out of the can, screw on the stopper. Watch what happens while the can cools. Why do the sides bend inwards? (Fig. 24.)

Something must be pressing from the outside, and there must be an absence of an equal pressure from the inside. As the tin and its contents cool, the steam in the can condenses to water and so occupies much less space. The air has already been driven out and no more can get in. Thus there is no air pressure inside but there is outside. This causes the tin to bend inwards. If the tin had been very strong it would have resisted

the outside pressure and we should not have noticed anything. The air cannot exert an unlimited pressure.

A striking demonstration of air pressure was that performed by OTTO VON GUERICKE of Magdeburg in 1650. Two hollow copper hemispheres each about one foot in diameter were fitted together, the junction having a ring of leather, so that they were perfectly air-tight, yet could easily be pulled apart. Air was removed by a suction pump from the globe. Two teams

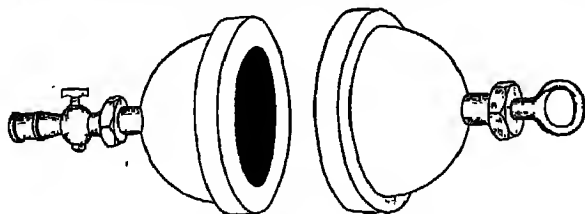


FIG. 25. Magdeburg hemispheres.

each of eight horses were fastened to the hemispheres, but were unable to pull them apart. As soon as air was allowed to enter the globe, the halves came apart quite easily.

A modern version of the apparatus is shown in Fig. 25.

MEASUREMENT OF THE PRESSURE OF THE ATMOSPHERE

Expt. 39. Fill a strong glass tube, 36 inches long and closed at one end, with mercury. Place the thumb over the open end, invert the tube, and place the open end under mercury in a dish. Now remove the thumb, allowing a free flow of mercury between the tube and the dish. What happens? Measure the height of the mercury column (keeping the tube vertical). Can any air be above the column of mercury? A space which does not contain anything whatever is called a *vacuum*. The space above the mercury column is for all practical purposes a vacuum. It contains only a very small quantity of mercury vapour and a little air. Both these are so small that for our present purpose they can be neglected. Allow the tube to tilt sideways. If you tilt the tube far enough the mercury will fill the tube but the vertical height will remain the same (Fig. 26). What keeps the mercury up? Allow a little air to enter from the bottom taking care that the whole of the mercury does not rush out. How is the height of the column affected by the entry of some air? Repeat the experiment using a wider tube. Is there any difference in the height of the column?

Find the weight of the mercury in the column as follows: Raise the tube which is standing with its open end under the mercury in the dish until the open end is almost level with the surface of the mercury in the dish. Close the open end with the thumb, remove the tube, and very carefully allow the mercury to flow into a previously weighed dish. Weigh on a good balance. If you weigh in grams (most good balances are provided only with metric weights) convert to lb. (454 gm. = 1 lb.). Divide the weight of the mercury by the area of the bore. In this way you obtain the weight of mercury that is pressing down on one square inch. Repeat the experiment with the mercury from another tube of different bore. Your two results should be about the same, allowing for unavoidable errors due to inaccurate measurements and weighings.

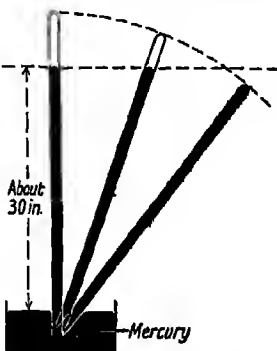


FIG. 26. Torricelli's experiment.

Weight of dish	.	.	.	.	.	.	.	x	gm.
Weight of dish + mercury	.	.	.	.	.	.	.	y	"
Weight of mercury	.	.	.	.	.	.	.	y-x	"
Diameter of the bore	.	.	.	.	.	.	.	d	in.

$$\text{Area of bore} = \frac{22 \times d^2}{7 \times 4} \text{ sq. in.}$$

$$\text{Weight of mercury per sq. in.} = \frac{(y-x) \times 4 \times 7}{22 \times 454 \times d^2} \text{ lb.}$$

The column of mercury in the last experiment was held up by the pressure of the air, and this must be equal to the weight of the mercury. This is about 15 lb. to the square inch.

We have seen that the pressure of the atmosphere can support a column of mercury about 30 inches high. We can easily calculate the height of a column of water it would support. Mercury is about 13.6 times as heavy as water, so a column of water 13.6 times 30 inches will be supported. This is over 30 feet. If we wished to perform a similar experiment with water instead of mercury we should need a tube about 36 feet long.

Experiment 39 was first performed in 1642 by an Italian named TORRICELLI, a pupil of Galileo. The vacuum over the mercury is often called a *Torricellian vacuum*.

An arrangement very much like Torricelli's was taken up a mountain and the height of the column noted. It was found that the higher the instrument was taken up the mountain the

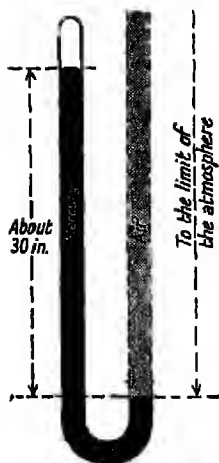


FIG. 27. The pressure of the air (at sea-level) will support a column of mercury 30 ins. high.

lower down the tube was the mercury level. This experiment shows that atmospheric pressure decreases as the height above the surface of the earth increases. We know that air can be compressed, and it is reasonable to suppose that the air at the surface of the earth is compressed by the weight of all the air on top of it. If you filled a room from floor to ceiling with cotton wool thrown in anyhow, and not specially packed, you would find that the cotton wool at the bottom would be more compressed than that at the top. If you cut out a cubic foot of the cotton wool at the bottom and weighed it, you would find that it weighed more than a cubic foot taken from the top. We live at the bottom of an ocean of air. At the bottom it is dense, but it gradually decreases in density from the bottom upwards, until finally it becomes so rare that it is impossible to tell whether there is any air present or not. Outer space is regarded as a vacuum.

THE BAROMETER

This is an instrument used for measuring the pressure of the atmosphere. There are many kinds, but most use Torricelli's principle. Fig. 27 illustrates a very common type of barometer. The height of the mercury is read (either in inches or centimetres) on the scale fixed behind the long tube of mercury. Fig. 28 shows another type in which the height of the column is registered on a dial. This type is not very accurate and the mechanism is liable to stick and often needs tapping before the needle will point to the correct height. Instruments of this type are often seen in the halls of houses, and usually suffer

from too much tapping. In addition to the scale to show the height of the mercury column there are such phrases as 'Rain', 'Change', 'Dry', 'Fair', 'Very Dry'. The implication is that at a certain height of the mercury column a certain type of weather will be experienced. Even the most casual observation will show that this is not true. The weather does not depend on the atmospheric pressure alone. Temperature and other factors also enter into it. The prediction of the kind of weather is very difficult, and cannot be reliable without an immense amount of information about weather conditions over a wide area (Ch. XXX). Nevertheless, it is true that when there is a rise of the barometer, as it is called, fine or calm weather is more likely than not; and when there is a fall of the barometer, rain or wind or both may reasonably be expected. The speed of the change is important, a slow steady rise being more favourable for fine weather than a quick rise. It is amusing and instructive to keep for a year records of the barometric pressure and the weather. The readings should be made daily at the same time. A chart like the one below might be used for keeping the record. Another convenient way of keeping a record of the barometer readings is to draw a graph.



FIG. 28. A mercury barometer used as a weather glass.

WEATHER CHART

Place.....Month.....Year.....Time of Reading.....

Date	Barometer reading		Wind		Rainfall in in.	Official forecast
	Height in in.	Change + or -	Direction	Strength		
				e.g. Calm Strong Gale		

THE ANEROID BAROMETER

Another type of barometer is the aneroid. In this no mercury or other liquid is used (Fig. 29). A thin metal box, exhausted of air, is the essential part of the instrument. When the atmospheric pressure changes, the sides of the box go in or come out according to the nature of the change. These movements are registered on a scale by means of a pointer. Aneroid baro-

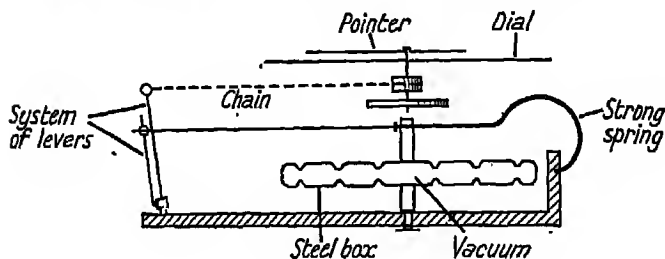


FIG. 29. The principle of the aneroid barometer.

meters are graduated by comparing them with a mercury barometer. The ordinary cheap aneroid barometer is not accurate, but some very good instruments are made on this principle. They are often very small and can easily be carried by climbers to give them some idea of the height they have reached. Some are used in aeroplanes for this purpose. They are called *altimeters* (Fig. 30). These instruments must not be relied on for great accuracy even if they register the correct atmospheric pressure, because other factors besides height affect the pressure of the atmosphere.

The pressure at any height depends partly on the pressure at sea-level vertically below it. If the pilot of an aeroplane regulates his altimeter when he takes off it will not necessarily read correctly when he wants to land at the same landing-ground because the pressure at sea-level may now be different. Even for such a small increase of pressure as 0.3 inch at the surface the altimeter reads almost 300 feet too high. If the pilot wishes to land at another place the pressure at the surface

might be different from that at his starting-point and his altimeter would not read correctly. It is very important for a pilot to know his exact height especially when the visibility is poor. He usually asks by radio for the ground pressure before he lands, and corrects his altimeter accordingly.

A very approximate estimate of the height of a mountain may be made by assuming that for every 900 feet rise there is a fall of 1 inch in the barometer reading. This can be only approximately true for small heights, because the fall in the pressure is not uniform. The pressure of the atmosphere depends on the weight of the air above the point of observation, and, as air is compressible, the density of the air decreases as the height increases. At 18,000 feet the pressure is about 15 inches, roughly half what it is at sea-level.

If the pressure, temperature, and amount of moisture in the air are known at the foot of a mountain, it is possible by the use of a complicated formula, to make a more accurate estimate of the height of a mountain.

So far, we have measured the pressure of the atmosphere by saying how many inches of a vertical column of mercury it will support. This measure is still commonly used, but a more useful standard, and one that is becoming more widely used, is the *millibar* (mb). This is the unit of pressure in the Centimetre-Gram-Second System. 1000 mb is the pressure of a column of mercury 29.531 inches long. Many barometers are now graduated in millibars.



FIG. 30. An altimeter.

APPLICATIONS OF AIR PRESSURE

1. The bicycle pump

Fig. 31 is a diagram of a bicycle pump. Note the washer at the end of the piston rod. It is kept greased. Note its shape.

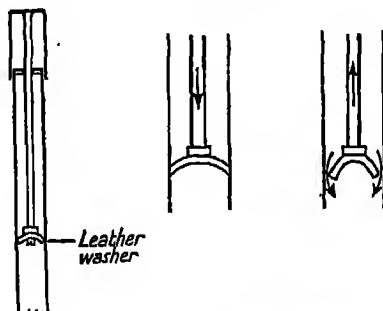


FIG. 31. The bicycle pump.



FIG. 32. A self-filling fountain-pen.

When the piston is withdrawn, air enters normally from the top, getting in front of the washer by passing between it and the side of the pump. The shape of the washer allows this to happen. When the pump is attached to a valve for the purpose of blowing up a tyre, air cannot enter by any other means than the one described; but when the pump is unattached, air enters through the hole which is usually the exit. It is only in the intake of air that atmospheric pressure comes into play.

2. The self-filling fountain-pen

Fig. 32 illustrates how such a pen is constructed. The ink reservoir is an india-rubber bag. When there is no ink in the reservoir it contains air. Against the rubber bag is a strip of

metal attached to a lever. When the latter is operated the metal presses against the bag forcing out most of the air. When the lever is moved the other way the bag resumes its shape because it is elastic. This reduces the pressure in the bag, and if the nib is in the ink the latter flows in to take the place of the expelled air. The pressure of the air on the surface of the ink outside the bag forces the ink to enter.

3. The garden syringe

Syringes, large and small, are used for many purposes. They all work on the same principle. We shall consider the garden syringe (Fig. 33).

Expt. 40. Examine a garden syringe and take it to pieces. Compare what you find with the figure.

The syringe is placed in the water with the piston at its lowest position. On pulling the piston up the barrel, water enters through the perforations. The air pressure on the surface of the water forces the water to enter the barrel where there is no downward pressure except perhaps a little from a small volume of air left in. When the syringe is removed from the water and the piston pushed down, the water is forced out of the barrel and in passing through the perforations becomes a fine spray.

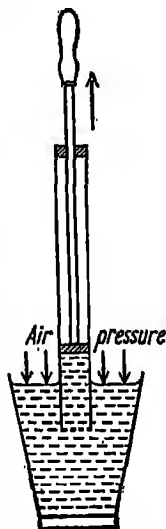


FIG. 33. A garden syringe.

4. The lift-pump (suction pump)

This is shown in cross-section in Fig. 34. An air-tight plunger moves in a cylinder. The plunger is operated by a rod moved by a lever. A pipe leads from the bottom of the cylinder to the water at the bottom of the well. There is a valve at the junction of the pipe and cylinder, and another valve in the plunger. When the pump is started for the first time there will be no water in the pipe or cylinder. On the first up-stroke the plunger valve closes (*Why?*), and the cylinder valve opens (*Why?*). The pressure of the atmosphere on the surface of the

water in the well is now greater than the pressure in the pipe. Water is forced up the pipe and some of it enters the cylinder. On the first down-stroke the plunger valve opens (*Why?*), and the cylinder valve closes (*Why?*). Water passes through the plunger valve. On the second up-stroke, the plunger valve

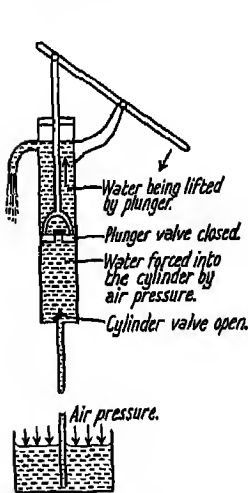


FIG. 34. The lift pump.

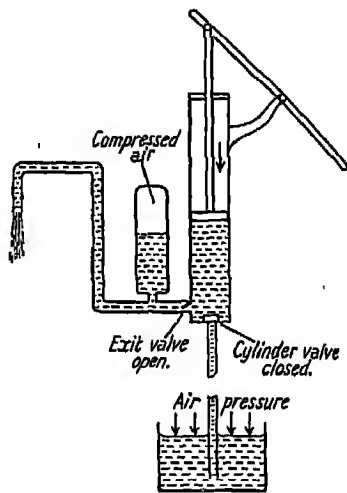


FIG. 35. Force pump with air compression chamber to give a continuous flow of water.

closes (*Why?*), and the cylinder valve opens (*Why?*). Water is lifted by the plunger and flows out through the spout, while at the same time more water is forced from the well into the pipe and cylinder. The water is raised by atmospheric pressure up to the top of the stroke of the plunger. From there it is lifted to the spout. The atmospheric pressure will support a column of water nearly 34 feet high, and theoretically it is possible to have a pump with the plunger at the top of its stroke nearly 34 feet above the surface of the water. In practice, however, owing to the plunger not being a perfect fit, and to other imperfections in the pump, the height seldom exceeds 27 feet.

5. The force pump

In this pump there is no valve in the plunger, but there is one leading from the cylinder to the exit pipe. On the first up-stroke the exit valve closes (*Why?*), and the cylinder valve opens (*Why?*). Water enters the cylinder (*Why?*). On the first down-stroke the cylinder valve closes (*Why?*), and the exit valve opens (*Why?*). Water is forced into the exit pipe. With this pump the water can be forced to a height depending on the strength of the pump. The supply of water, however, is intermittent, the water being delivered on the down-strokes only. Modern force pumps are made so that a steady flow of water is obtained. This is done by arranging an air chamber in connexion with the exit pipe. Fig. 35 illustrates the principle. The water is forced past the exit valve and this compresses the air in the chamber. On the up-stroke the compressed air forces some water out of the exit pipe.

6. Fire-engine pumps

It is sometimes necessary in case of fire to force water to the top of a high building. In the Great Fire of London, 1666, the only known fire engine was a brass hand squirt 30 inches long. It was worked by three men, two of whom held it by the sides while the third drew in the water from a leather bucket. The squirt was then pointed towards the fire by the two men while the third squirted the water as best he could. It was, of course, totally inadequate. Many modern fire engines are pumped by a petrol motor. One type, of 50 h.p., can pump 350 gallons per minute; another, of 75 h.p., can deliver 600 gallons per minute. The object is to reach as great a distance as possible with an unbroken stream of water. A long hose enables the water to be taken as near as possible to the fire before issuing from the nozzle, but the resistance offered to the water in passing through the hose seriously reduces the pressure of the water and limits the distance through which the water can be forced. Some modern fire engines use a hose from 500 to 600 yards long.

THE COMPOSITION OF THE AIR

We know that the air is a gas exerting a pressure of about 15 lb. to the square inch in all directions. What is the nature of this gas? Is it one gas or is it a mixture of gases? If so, how many? And what are the properties of these gases? We shall begin to study the composition of the air by trying to find out what changes take place when substances burn in the air. It was only when men began to study burning that they were able to discover the nature of the air. From early times men must have noticed that air had some connexion with burning. Unless a fire has air it will go out; and if air is forced into a fire it will burn more vigorously. We shall then consider burning in the hope of learning something about the composition of the air.

ELEMENTS

We must start by burning simple substances, and at present you do not know which substances are simple and which are complex. There are a number of substances which have not been split up by purely chemical means. Such substances are called *elements*. An element is a substance which so far has not been split up into anything simpler. The chemist has reason for believing that these substances are incapable of further decomposition. They are supposed to be true simple substances. Sulphur is a common element. If anyone asks what sulphur is, it is impossible to answer him. We can describe sulphur to him, but we cannot tell him of what sulphur is made. It is simply made of sulphur. Carbon, an impure form of which is charcoal, is another element, and so is copper. The elements can be divided into two classes—*metals* and *non-metals*. No doubt you have a rough idea of what a metal is. We shall have to study the differences between metals and non-metals later.

THE BEHAVIOUR OF SOME ELEMENTS WHEN HEATED IN THE AIR

1. Magnesium

Expt. 41. Examine a piece of magnesium ribbon. Describe its appearance. Scrape it with a knife. It is a silvery, white substance. Hold one end of the ribbon in the tongs and put the other end in the bunsen flame. What happens? Withdraw the magnesium from the flame when it is alight. Describe the light. What is left? It is sometimes called the *calx* of magnesium.

Where has the calx come from? Remember it cannot be a simpler substance than the magnesium, because the latter is an element. We must leave the problem of the composition of the calx for a short time.

2. Copper

Expt. 42. Use copper foil (very thin sheet copper). Note again the metallic lustre and the colour. Hold it in the bunsen flame with the tongs. Does it take fire as did the magnesium? Keep it in the flame and note the colour changes. Take it out of the flame and watch the colour change as it cools. What colour is it now? Scrape it with a penknife and note the copper beneath the black film. Perhaps you noticed this film flickering about in the flame when you were heating it. After scraping off as much of the black substance as possible, heat the copper again. Note that the black film re-forms. Scrape it again and re-heat. Continue to do this until nearly all the copper has disappeared.

The black substance was copper calx. Unlike the calx of magnesium, it formed a protective film on the copper which prevented the rest of the copper from being changed into the calx.

3. Lead

Expt. 43. Put a little lead foil on a crucible lid and heat it. What happens? After it has melted stir it about with a glass rod. Does the lead disappear? What appears in its place? Note the colours of the substances formed. Lead calx is yellow, but sometimes there is a little red, orange, grey, and green.

4. Sulphur

Expt. 44. Put a little powdered sulphur on a spoon. Sulphur is an element, but not a metal. Hold the spoon over the flame of the bunsen carefully and describe what happens. [Literally &]

There is much to see. The sulphur first melts into a yellow liquid which quickly changes to a red-brown liquid. (Sometimes when heated in this way it changes to the red-brown liquid without first becoming yellow.) It then takes fire, burning with a blue flame, and giving off choking fumes which should be avoided after cautiously smelling them. There is no calx left. The term calx is reserved for the substance left when a metal burns in the air. As far as we can see there is nothing left, but our sense of smell tells us that there is something in the air which may be the result of burning the sulphur.

5. Carbon

Expt. 45. Put some charcoal on a crucible lid. Charcoal is an impure form of the element carbon (a non-metal). Describe what happens when it is heated.

The charcoal becomes red hot but does not burst into flame. It finally disappears except for a very light ash. This is the impurity in the carbon. If you performed the experiment with a pure form of carbon, such as lamp-black, no ash would be left. We can say then that when carbon is heated in the air it disappears, so far as we can see. There is not even a smell.

Let us consider these results. We have heated five elements in the air and all have behaved differently in some respects. In the first three there was a solid substance left. In the case of sulphur we suspect that there was a gas formed because of the smell. In the case of carbon we have no reason to suspect that anything solid or gaseous was left. On the other hand it is possible that a colourless and odourless gas was given off.

Let us first deal with the substance that was obtained when magnesium was heated in the air. It was a white powder. Of what does it consist? It does not look like magnesium and is not magnesium as we know it. We know, however, that magnesium must have something to do with its composition because it was made from that metal. When other metals were used the substances obtained looked nothing like magnesium calx. Has the air anything to do with its composition? We can test this by heating some magnesium in the absence of air.

Expt. 46. Put a spiral of magnesium ribbon in a hard glass tube with a tap at each end as shown in Fig. 36. Exhaust the tube of air by means of an exhaust pump. Heat with a Ramsay burner (shown in the diagram). Heat gently at first and increase the heat gradually otherwise the tube may crack. What happens? Probably you will see some sparks and a little of the magnesium burning for a short time, but the bulk of the metal will just become red hot and will not take fire. No calx, or only a very little, will be formed. Now open both taps and allow air to enter. What happens? Close both taps again. Does the magnesium continue to burn?

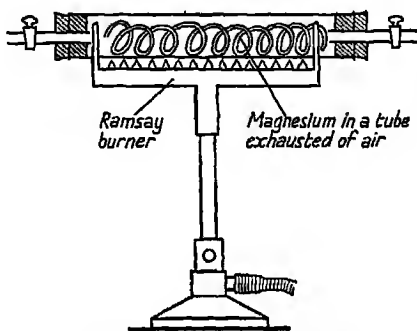


FIG. 36. Magnesium heated in the absence of air.

From this experiment it is clear that magnesium will not burn in the absence of air, and it will burn when air is present. The reason it burned a little when the tube was exhausted of air was that the tube cannot be completely deprived of air in this manner. When the air was prevented from entering while the magnesium was burning, the magnesium soon stopped burning. As magnesium calx cannot be formed in the absence of air, we may conclude that the air has something to do with its composition.

You can heat lead, copper, and carbon in the absence of air very simply by burying them in fine sand tightly packed in crucibles. (Under these conditions there is not enough air present to affect the experiment.) The crucibles are then heated. You will find that the lead melts but forms no calx;

the copper also forms no calx, and the carbon is unchanged. Air seems to be necessary for burning, and a metal does not form its calx in the absence of air.

We still do not know what magnesium calx is. When the magnesium changed into a calx, did it gain or lose anything? It is difficult to believe that it lost anything, because magnesium is an element, and the calx, whatever it is, cannot be simpler than magnesium. The way to find out if magnesium changes in weight when heated in the air is to weigh the substance before and after burning.

Expt. 47. Does magnesium increase in weight when heated in the air? Weigh a crucible and lid. Place in it some magnesium ribbon cut into small pieces. Weigh the crucible, lid, and magnesium. Place the crucible covered with its lid on a pipe-clay triangle resting on a tripod. Heat, gently at first, but gradually more strongly until the crucible is as hot as the flame can make it. Using the tongs, raise the lid for as short a time as possible to see if the magnesium is burning. You will find that as you raise the lid the magnesium burns, because air enters. Occasionally raise the lid very quickly, but as far as possible prevent the loss of smoke, which is really magnesium calx. When all the magnesium appears to have been changed to calx, remove the lid altogether and continue to heat strongly for about five minutes with the air free to enter the crucible. Cool (gently, or the crucible may crack) and weigh. Complete a table of results as follows:

Weight of crucible+lid	gm.
Weight of crucible+lid+magnesium	"
Weight of crucible+lid+magnesium calx	"
Gain (or loss) in weight	"

There is a gain in weight. Where does this extra matter come from? We know that magnesium will not burn without air, and that it gains in weight when heated in the air. Does the magnesium take something from the air to form a calx? To answer this question must be the object of our next experiment.

Expt. 48. Stand a graduated bell-jar in a trough of water (Fig. 37). To the stopper of the bell-jar fasten a spiral of magnesium. Heat the latter in a flame until it takes fire, then put the stopper on the bell-jar and allow the magnesium to burn inside. Note what happens to the level of the water in the bell-jar. At first the water level falls

because the air in the jar is heated and expands. When all is cool, note the level of the water in the bell-jar and compare it with the level outside. The water in the bell-jar rises and consequently the level outside falls a little. This, however, is a very small amount if the amount of water in the trough is large compared with that in the bell-jar.

What caused the water to enter the bell-jar? There must have been a reduction of pressure inside and the air pressure out-

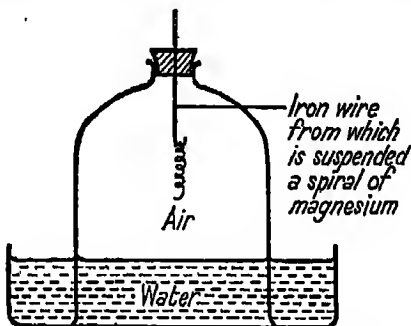


FIG. 37. The burning of magnesium in a bell-jar.

side caused the water to enter. The volume of the magnesium and calx can be neglected, for it is very small compared with that of the air in the bell-jar. The water rises about one-fifth of the height of the bell-jar above the level of the water outside. There is some magnesium left unburned. This means that the flame did not go out for lack of magnesium, but for lack of air. Yet there is still some air in the bell-jar. How can we account for this? Evidently the air that is left in the jar will not allow magnesium to burn in it, but ordinary air will. The air left in the bell-jar must be different from ordinary air. There must be a part of the air that helps magnesium to burn, and another part that will not let magnesium burn in it. Test the air in the jar with a lighted taper. It is put out.

COMPOSITION OF THE AIR

Some elements burn in air, others do not. Those which do, behave like magnesium. They use up part of the air in burning and form a new substance. In the case of a metal this is called the calx. The new substance formed in the case of sulphur is a colourless gas; in the case of carbon it is a colourless and odourless gas. It seems then that the air consists of two parts, one that helps burning and is used up in the process, and one that does not help burning. The gas that helps burning is called *oxygen*. The part that does not help burning consists largely of a gas called *nitrogen*. There are traces of a few other gases as well, one of them, though present in very small quantities, being of the utmost importance to living organisms. About one-fifth of the volume of the air is oxygen and the other four-fifths largely nitrogen. The experiment we performed with the bell-jar was not exact enough to show this volumetric composition, but the result indicated that proportion. Accurate experiments have been made to find the composition of the air by volume, and it is found that its composition varied very slightly from time to time, and from place to place.

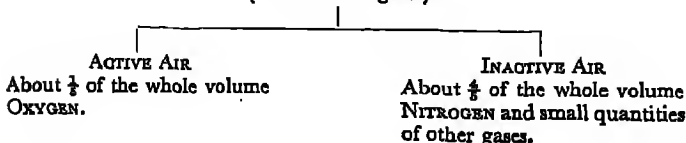
Expt. 48a. To find the proportion of oxygen in the air.

Pour a solution of pyrogalllic acid (pyrogallol) into the bottom of a long graduated tube. Quickly drop in a pellet of caustic potash to make it alkaline and insert a rubber stopper. The solution absorbs oxygen and turns brown. Shake up the solution for a few minutes and then remove the stopper while the end is under water. (See that the levels of the liquid are the same.) Water enters the tube taking the place of the oxygen absorbed. Measure this volume and compare it with the original volume of air in the tube. (Actually the *very small amount* of carbon dioxide in the air is absorbed, see p. 74.)

We shall return to the composition of the air later (Ch. XLV).

COMPOSITION OF THE AIR

(A mixture of gases)



MIXTURES AND COMPOUNDS

We know what an element is, and it is clear that magnesium calx cannot be an element, because it is not a simple substance but consists of a combination of magnesium and oxygen. The properties of the calx are quite different from those of either magnesium or oxygen. No one seeing magnesium calx would suspect from its appearance that it was partly made up of the silvery-white metal magnesium, much less would they suspect that oxygen, a colourless, odourless gas, was part of its composition. Such a substance is called a *compound*. It is not merely a *mixture* of substances; the substances are *combined* and the result is a substance quite different from either of the constituents. The differences between compounds and mixtures are very important and it will be impossible to understand any further chemistry unless the nature of a compound is understood. Let us take another example and try to make the subject clear.

Expt. 49. Mix some iron filings and some powdered sulphur.

You have now a mixture of iron filings and sulphur. You can still see the particles of iron and sulphur. The colour of the mixture is intermediate between the colour of iron filings and sulphur. You can separate the constituents quite easily as we did in Experiment 9 by dissolving the sulphur in carbon disulphide in which the iron is insoluble; or, by drawing a magnet through the mixture, when the iron will cling to the magnet and the sulphur will be left behind; or, by placing the mixture in water so that the sulphur will float while the denser iron sinks to the bottom.

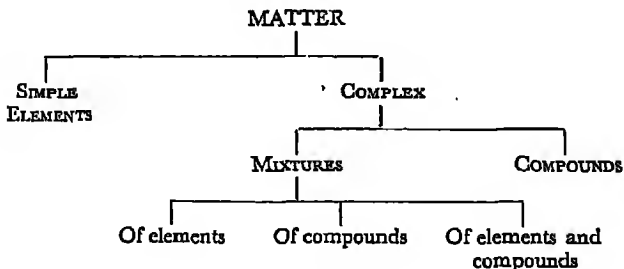
How much iron is present compared with the amount of sulphur? A pound of one mixed with (say) seven pounds of the other would be called a mixture, but so would any other proportion.

Expt. 50. Put the mixture of iron filings and sulphur in a crucible without a lid and heat. When the mass begins to glow brightly remove the flame. The action will continue, heat being given out. When the mass is cool, remove it from the crucible and examine it.

It is a grey mass not like iron or sulphur. You cannot now

see particles of the constituents present. You cannot separate the iron from the sulphur by a magnet, or by dissolving out the sulphur in carbon disulphide, or by sedimentation in water. The new substance, which is called iron sulphide, has properties different from those of either of its constituents and different from those of a mixture of its constituents. When formed, heat was evolved, and this was not so when iron and sulphur were simply mixed. In iron sulphide the constituents are combined in a definite proportion. The experiment just performed does not prove this, but it can be proved. The iron sulphide is a compound of iron and sulphur and not a mixture. A compound of an element with sulphur is called a *sulphide*; a compound of an element with oxygen is called an *oxide*. The modern name for magnesium calx is magnesium oxide. All calces are oxides.

A mixture (the constituents of which may be in any proportion) may consist of elements alone, or elements mixed with compounds, or compounds alone. No heat is formed when mixtures are made, and they are usually easily separated by mechanical means. When a compound is formed or decomposed, a chemical action takes place and this is accompanied by a gain or loss of heat which is usually, but not always, obvious.



OXYGEN

We must now study individually the gases which are found in the air. When some compounds are heated they decompose and give off oxygen. This gas was first obtained in this way by PRIESTLEY (1774). He directed the rays of the sun by means of

a 'burning glass' on to some red calx of mercury. We now know this substance to be mercuric oxide, that is, a compound of the elements mercury and oxygen.

Expt. 51. Heat strongly a little mercuric oxide in a hard glass test-tube. Note the change in colour. What do you notice on the sides of the test-tube? Put a glowing splint of wood into the mouth of the test-tube. What happens to the glowing splint? Does anything happen to the gas which is coming off? How do you know a gas is being evolved? Does the mercuric oxide finally disappear? What is left in the test-tube? Pour it out on to a piece of paper and examine it.

When mercuric oxide is heated it decomposes into mercury and oxygen.

Mercuric oxide = Mercury + Oxygen.

Not many oxides evolve oxygen on heating. Magnesium oxide does not. Some metals form more than one oxide, e.g. brown lead peroxide contains more oxygen than the yellow lead monoxide. On heating, lead peroxide yields oxygen and lead monoxide. Manganese dioxide also yields oxygen but only when very strongly heated.

There are some other compounds, not oxides, but rich in oxygen which yield oxygen on heating, e.g. potassium permanganate, potassium chlorate, and potassium nitrate.

Expt. 52. Gently heat a few potassium permanganate crystals in a hard glass test-tube. Test with a glowing splint for the evolution of oxygen.

Expt. 53. Crush some potassium chlorate into a powder and heat it in a hard glass test-tube. What happens to the powder at first? What happens on further heating? How do you know a gas is being evolved? Test for oxygen with a glowing splint. When no more oxygen comes off allow the liquid in the test-tube to cool. What does it look like? Compare it with the potassium chlorate with which you started. The substance left is called potassium chloride.

Potassium chlorate = Potassium chloride + Oxygen.

Potassium chlorate is a compound of three elements, potassium, a metal, chlorine, a green gas, and oxygen. Potassium chloride is a compound of only two elements. The termination -ide indicates in chemistry a *binary compound* (that is, a compound of two elements). The two elements in potassium chloride are potassium and chlorine.

It is found that when potassium chlorate and manganese dioxide are mixed together, the mixture when heated evolves oxygen at a temperature much lower than that at which either of the constituents evolves the gas. When the action is completed, the potassium chlorate has changed to potassium chloride, but the manganese dioxide is the same at the end of the action as it was at the beginning. All the oxygen comes from the potassium chlorate and none from the manganese

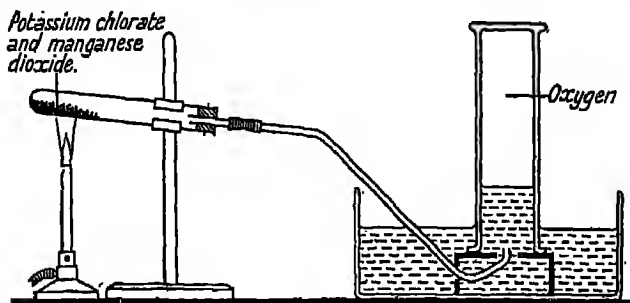


FIG. 38. Preparation of oxygen.

dioxide. In some way which is not fully understood, the manganese dioxide causes the potassium chlorate to give off oxygen at a much lower temperature. A substance which causes a chemical action to take place at a quicker rate or at a lower temperature than it otherwise would do is called a *catalyst*. The process is called *catalysis*. At the end of the action the catalyst remains unchanged.

THE PREPARATION OF OXYGEN

Expt. 54. Mix some powdered potassium chlorate with a third of its weight of manganese dioxide. (Never grind up potassium chlorate with another substance, as an explosion may occur.) Put the mixture in a hard glass boiling tube. Arrange the apparatus as in Fig. 38. The boiling tube should slope slightly towards the mouth, and then any moisture formed will flow towards the cooler part of the tube and so avoid cracking it. Arrange the delivery tube to pass under a beehive shelf standing in water in a pneumatic trough. On the beehive shelf stand an inverted gas-jar full of water. To do this, fill the gas-

jar with water and put on the lid. Keep the lid on with one hand and invert the jar with the other. Place the mouth of the jar under water in the pneumatic trough and then remove the lid. The water will not now come out. Stand the jar on the bee-hive shelf. Heat the boiling tube. Soon bubbles of gas appear in the gas-jar. The oxygen formed in the tube passes through the delivery tube and into the water under the bee-hive shelf. There it is directed into the gas-jar, the water in which is forced down. At first air comes into the gas-jar and not oxygen, because there was air in the apparatus before oxygen was evolved. Soon all the gas that enters the jar is oxygen. When one jar is full of the gas, replace the lid, under water, and put another inverted jar over the bee-hive shelf. This second jar should be standing on the bottom of the pneumatic trough ready for use. If a jar of the gas free from air is required, use the second jar and not the first. This method of collecting a gas is called collecting over water.

THE PROPERTIES OF OXYGEN

We have already learned some of the properties of the gas during the preparation and collection. It is a colourless, odourless gas. If it is soluble in water at all, it is only slightly so, otherwise we could not collect it over water. We also know that it relights a glowing splint and does not itself take fire like coal gas. Let us see what happens when we burn some elements in oxygen.

Expt. 35. Place a little sulphur in a deflagrating spoon and hold it in the bunsen flame until it is alight. Now place it in a jar of oxygen (Fig. 39). What happens? How does this differ from sulphur burning in air? Remove the spoon; pour a little water into the jar; replace the lid and shake. Add a little blue litmus solution. It turns red.

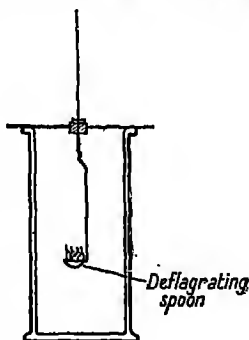


FIG. 39. Sulphur burning in a jar of oxygen.

This is because an acid is now present. When an acid is added to blue litmus solution the latter turns red. Leaving for the present the question of what an acid is, let us consider what happened in our experiment. The sulphur combined with oxygen to form an oxide, and a considerable amount of heat

was evolved in the process. The oxide formed is called sulphur dioxide. (We shall see later why we call some oxides *di*-oxides.) When the sulphur dioxide was shaken with water some of it combined with the water to form sulphurous acid.

(1) Sulphur + Oxygen = Sulphur dioxide.

(2) Sulphur dioxide + Water = Sulphurous acid.

Expt. 56. Put some carbon in a deflagrating spoon and heat it until it glows red. Place it in a jar of oxygen. Compare what happens with the burning of carbon in air. Remove the deflagrating spoon; add a little water to the jar, replace the lid, and shake. Add litmus solution. It is turned red. How does the colour compare with that in the previous experiment?

(1) Carbon + Oxygen = CARBON DIOXIDE.

(2) Carbon dioxide + Water = CARBONIC ACID.

Expt. 57. Burn some more carbon in oxygen to obtain carbon dioxide. Add lime-water and shake.

The lime-water turns milky. We may use this as a test for carbon dioxide.

When the English chemist PRIESTLEY discovered the gas which we now know as oxygen, he informed a famous French chemist, LAVOISIER, of his discovery. Lavoisier proved that the gas Priestley had obtained from red calx of mercury was a constituent of the atmosphere. He heated mercury for some days in the presence of air, using an apparatus by which he could observe what fraction of the air was used up (Fig. 40). He obtained a red powder and noticed that some of the air had disappeared. He measured the volume of the air lost. He now heated the red powder and recovered the mercury. In addition he obtained some of Priestley's gas, the volume of which was equal to the volume of the air lost. He concluded that the mercury had combined with some gas from the air to form red calx of mercury, and then, on heating, the calx had evolved the gas again. Priestley's gas must therefore be a constituent of the air.

Lavoisier burned sulphur, carbon, and other non-metals in this gas and dissolved the compounds thus formed in water.

He found that in each case an acid was formed. He also found that this gas was a constituent of many other acids. He thought this new gas was an essential constituent of all acids, so he called the gas *oxy-gen*, which comes from two Greek words meaning 'acid maker'. Since Lavoisier's time we have found that some acids have no oxygen in their composition. The gas now called oxygen is badly named, but the name has not been altered

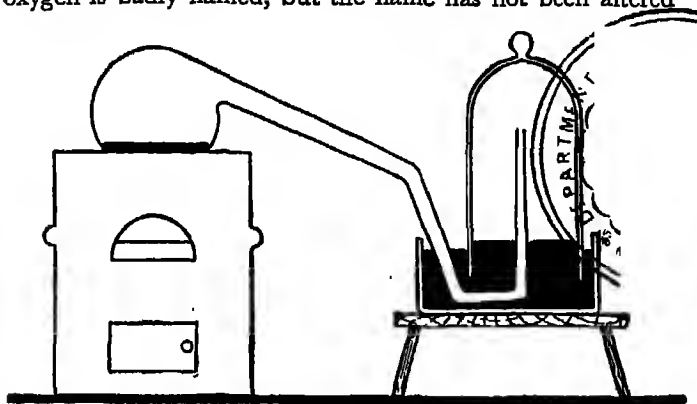


FIG. 40. Lavoisier's apparatus.

because so many people have got used to it. It does, however, serve to remind us that the oxides of some non-metals when combined with water form acids. Such oxides are appropriately called *acidic oxides*.

So far we have burned only non-metals in oxygen; let us now burn a metal in that gas.

Expt. 58. Fasten a spiral of magnesium ribbon to a deflagrating spoon. Light it at the bunsen flame and place it in a jar of oxygen. Compare what happens with the burning of magnesium in air. Examine the substance left in the jar. It is magnesium oxide. Shake it up with water. It does not appear to have dissolved, but a little may have done so. Divide the water in which the oxide has been shaken into two parts. To one part add blue litmus solution; to the other add reddened litmus solution. (Made by adding a drop of acid to blue litmus solution.) Compare what happens with what happened with a non-metallic oxide.

The red litmus turned blue. We have not obtained an acid this time, but something which has the opposite effect on litmus. Such a substance is called an *alkali*. We must leave till later the question of what is meant by an alkali. For the present we can think of it as having properties which are the opposite of those of an acid.

The properties of oxygen are as follows:

It is a colourless, odourless gas.

It is slightly soluble in water (4 c.c. of oxygen dissolve in 100 c.c. of water), but not so soluble as to prevent its collection over water.

It does not burn.

It relights a glowing splint. Substances burn in it much more readily than they do in air.

Non-metallic elements which burn in oxygen form oxides which with water form acids.

Metals which burn in oxygen form oxides some of which form alkalis with water.

OXIDATION AND COMBUSTION

When an element combines with oxygen it is said to be oxidized. *Oxidation* is the combining of oxygen with an element or compound (p. 153). When a substance burns in oxygen or air, either it is oxidized completely, or some of its constituents are oxidized, the others not being affected. Burning is oxidation. When a fire is burning in a room, the carbon in the coal is being oxidized to form carbon dioxide, and the other constituents of the coal are being oxidized to form other substances. When burning takes place heat is evolved. All chemical actions are accompanied by a gain or loss of heat. When oxidation takes place heat is evolved, but the process may take place so slowly that ordinary observation would not detect any rise in temperature, but heat is being given out nevertheless. Delicate methods of measuring heat have proved this. The term burning is used for oxidation when there is an obvious evolution of heat. The term *combustion* includes this, and also slow oxidation, when the evolution of heat is by no means obvious. This is called *slow combustion*. The term

'combustion' is also often used for any chemical action accompanied by heat and light. Light often accompanies oxidation. This occurs when the heat evolved is sufficient to raise the temperature of the body or the products of the combustion to the point at which light is emitted. It sometimes occurs with little or no heat.

THE RUSTING OF IRON

The rusting of iron is of great practical importance, but it is

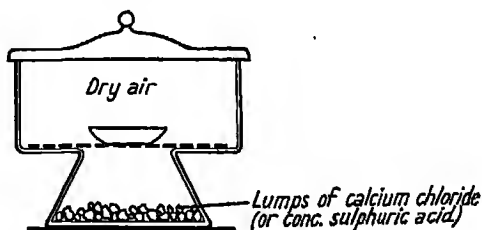


FIG. 41. A desiccator.

also interesting because it helps us to understand slow combustion or oxidation. We know from experience that iron rusts if left long enough in the open air, and that it rusts much more quickly in damp weather. It is clear that water must have something to do with rusting, but has air? To make things clearer let us try to find answers to the following questions by means of experiments:

1. Does iron rust in air free from water vapour?
2. Does iron rust in air containing water vapour?
3. Does iron rust in water free from air?
4. Does iron rust in water containing dissolved air?

Expt. 59. Does iron rust in air free from water vapour? Wash some iron filings in ether to free them from the oil with which they are usually contaminated. Put some of the filings in a dish which should then be placed in a desiccator (Fig. 41). Put some more of the filings in another dish left exposed to the ordinary air, which contains moisture.

A desiccator is a vessel of two communicating compartments,

one of which contains a substance such as concentrated sulphuric acid or calcium chloride. These substances have the property of taking moisture from the air. When one of these substances is placed in the bottom compartment of a desiccator and the ground glass lid is put on, the air in the upper compartment becomes dry in a short time. It remains dry so long as the air-tight lid is kept on. If any substance containing moisture is placed in a desiccator, it will give its moisture to the dry air, but this will soon lose it to the sulphuric acid. If anything dry is placed in a desiccator it will remain dry.

After a few days the filings exposed to both air and water rust, but those exposed to air only do not rust.

Expt. 60. Does iron rust in water free from dissolved air? Boil some distilled water in a flask. Watch it carefully as the temperature increases from that of the room to boiling-point. Notice any bubbles formed and observe where they burst. Do they burst before they leave the water or when they leave it? Can you distinguish between bubbles of air and bubbles of water vapour? Air dissolves in water, but as the temperature of the water increases less air is dissolved. This is different from what we learned about solids, which are usually more soluble in hot water than in cold. After the water has been boiling for a few minutes, and steam is issuing from the mouth of the flask, drop in a few bright nails. Remove the flask from the flame and, before steam stops coming out, fix a rubber stopper firmly in the mouth of the flask. Leave for a few days. As a control, put bright nails in distilled water in a flask, but do not expel the air. Leave for the same length of time as the other flask. The nails in the first flask do not rust, but those in the control do.

The boiling drives all the dissolved air out of the water and the steam drives all the air out of the flask. The nails are in contact with water only.

Iron will not rust unless both water and air are present.

The next question which arises is: What part does the air take in this process of rusting?

Expt. 61. Wet the inside of a gas jar with water and shake in some iron filings. These will stick to the inside of the jar. Remove any superfluous filings and invert the gas jar over water in a pneumatic trough. Contrive, by allowing a little air to leave, to get the level of the water the same inside and outside the jar (Fig. 42). Leave for a few days. The iron rusts and the level of the water in the jar rises. Measure the rise and compare the volume of the air lost with the

total volume. How does this compare with the amount of oxygen used in burning in Experiment 48? Put a lid over the mouth of the jar while it is under water. Remove the jar and put in a lighted splint. The light is put out and the gas left does not burn.

It is the inactive part of the air that is left. The oxygen was used by the iron in rusting.

When iron rusts it combines with the oxygen of the air and is oxidized. It is a process of slow burning or combustion, and although there is no obvious evidence of heat being given off,

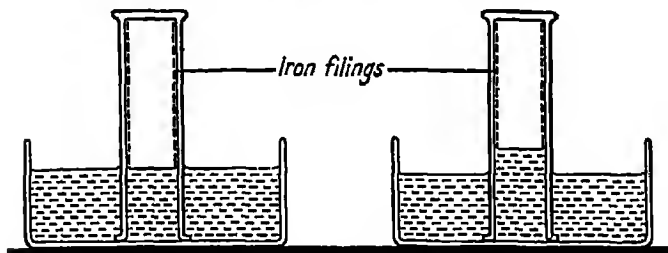


FIG. 42. The rusting of iron.

it has been found that in fact heat is evolved, but so slowly that it is lost before ordinary methods can detect it. But iron rust is not iron oxide. When iron has been rusting for a long time the final product is iron oxide combined with water. What we have said about iron rusting is true so far as it goes, but we have not told the whole story. It is really a very complicated process.

Iron is prevented from rusting by being covered with anything that will exclude air and water. Painting, smearing with oil, and keeping well polished are effective methods. Ironwork is painted primarily to preserve it; decoration is a secondary consideration. Iron is sometimes covered with a film of tin or zinc. These metals do not rust and keep the iron from rusting. Electro-plating, especially chromium plating, is very effective.

NITROGEN

We must now study the other main constituent of the air, the inactive part, which consists mainly of the gas nitrogen. How may this be obtained from the air so that we can study it

by itself? If we remove the oxygen from air, the gas left will be largely nitrogen, the other gases present being very small in amount. We shall see later how it is possible to remove one of these gases from nitrogen obtained from the air. Pure nitrogen may be obtained by chemical means. We shall study at present the nitrogen obtained from the air by the removal of oxygen.

Expt. 62. To obtain nitrogen from the air. Pass air over heated copper turnings and collect the gas. Arrange the appara-

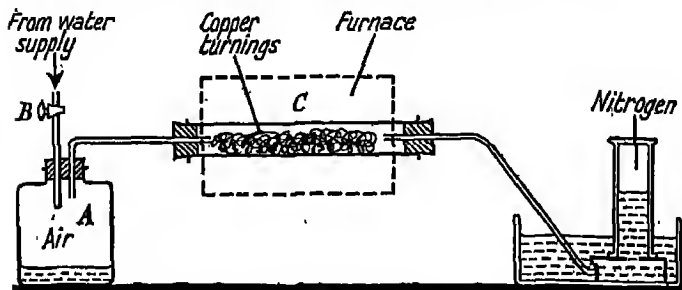


FIG. 43. Preparation of nitrogen from the air.

tus as in Fig. 43. Air is contained in the large vessel *A*. It is made to pass out of *A* by turning the tap *B* and allowing water to enter *A*. The air passes over copper turnings contained in a hard glass tube which is heated in a furnace *C*. The oxygen in the air combines with the copper to form a black compound, copper oxide. (We met this compound before when we heated copper in the air.) The gas left, largely nitrogen, is collected over water, in the same way as we collected oxygen. Collect several jars full. The gas will, of course, be wet.

PROPERTIES OF NITROGEN

Some of these properties we already know from its preparation and collection. It is a colourless, odourless gas. If it is soluble in water at all it is only slightly soluble. We know this because we collected it by passing it through water.

Expt. 63. Put a lighted splint into a jar of the gas. The light is put out and the gas does not burn. How does this gas differ from oxygen? Try to burn other substances in the gas in the same way as you burned them in oxygen.

Nitrogen is said to be a non-supporter of combustion. It is better to mention the things that will not burn in a gas rather than to make sweeping statements like this. It is true that the gas nitrogen is chemically inactive, that is, it will not readily combine with other substances. This may appear strange to you later on, when you learn that many of the compounds of nitrogen are very active indeed (Ch. XV).

CARBON DIOXIDE

When we heated carbon in oxygen we obtained a gas which turned lime-water milky. This gas we called carbon dioxide. When carbon burns in the air this gas is formed. Carbon in many forms (coal is one impure form) is often being burned or oxidized, and the carbon dioxide so formed enters the air. We shall see later other ways in which carbon dioxide enters the air. Although the amount of carbon dioxide in the air is small compared with that of oxygen and nitrogen, it is easy to show that it is present.

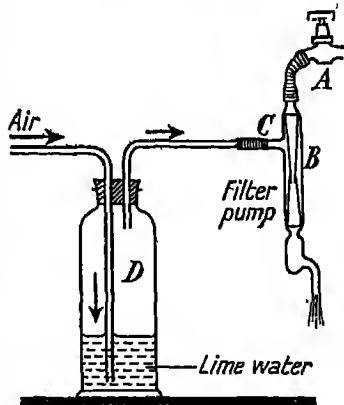


FIG. 44. To show that there is carbon dioxide in the air.

Expt. 64. To show that air contains carbon dioxide. Leave a dish containing some clear lime-water exposed to the air for a few hours. Watch the surface of the lime-water. A white film will appear on it. Stir the lime-water with a clean glass rod. It appears milky. The carbon dioxide in the air, by reacting with the lime-water, formed the white film. It is this substance distributed through the liquid that causes lime-water to appear milky.

Another way to demonstrate that there is carbon dioxide in the air is to fit up an apparatus as in Fig. 44. Turn the tap A. Water enters the filter pump B and draws the air out at C. The air bubbles through the clear lime-water in D. Note how long it takes before the lime-water turns milky.

Carbon dioxide can be obtained in other ways besides heating carbon in the air or in oxygen. Let us examine a substance from which carbon dioxide is very easily obtained, chalk.

CHALK

Examine some chalk. Grind it into a powder. Rub some between the fingers. Put a little on a glass slide and examine it under a microscope.

It is a soft, white solid, apparently non-crystalline. (When a



FIG. 45. The shells of some of the microscopic animals found in chalk.

substance is non-crystalline we say it is *amorphous*, that is 'without form'.) Much chalk that we buy to-day is not natural chalk; it has been artificially prepared. There are immense deposits of natural chalk in England. There is much under London, and more forming the South Downs. It is seen at the surface in the cliffs of Dover. When artificial chalk is examined under the microscope the small particles have no particular form, and there is very little to see under the microscope that we cannot see by the unaided eye; but when we examine natural chalk under the microscope we see that it is made up of tiny shells of many different shapes (Fig. 45). They are the shells of dead animals. Similar shells are dredged from the bottom of the sea to-day, so it is believed that the chalk beds were formed under the sea and have been raised to their present positions in the course of ages. Let us continue our examination of chalk.

Expt. 65. Is chalk soluble in water? Sprinkle a very little chalk in a beaker of water. If you put a large quantity of chalk into a little water, it is impossible to say whether any has dissolved or not; but with a little chalk in much water you should be able to see that if chalk is soluble at all it must be only very slightly soluble. Heat the water. The chalk remains undissolved. From this experiment it is impossible to say definitely that chalk is insoluble in water, but careful experiments show that in freshly distilled water chalk is insoluble.

The action of dilute acids on chalk

The common acids are: hydrochloric acid, nitric acid, and sulphuric acid. We shall have to study these acids later. For the present it will be sufficient for us to understand that a dilute acid is one that has been added to a quantity of water.

Expt. 66. Add dilute hydrochloric acid to a little chalk in a test-tube. A colourless and odourless gas is evolved so quickly that it causes a frothing of the mixture of chalk and acid. This is called an effervescence. Put a lighted splint into the mouth of the test-tube. The light goes out and the gas does not burn. Add more acid. Is more of the gas given off? Does the chalk disappear as if it had dissolved? You can test this better by dropping a very little chalk into some of the acid in a test-tube. A clear, colourless solution is left.

Add dilute nitric acid to some more chalk. Compare the result with that obtained when hydrochloric acid was used. Is there any apparent difference? Remember that when there is no apparent difference, as in this case, there may be a difference which we do not at present appreciate.

Now add dilute sulphuric acid to more chalk in a test-tube. Note the effervescence and test the gas as before. What is left in this case? How does it differ from what was left in the other two cases? Is the white substance left chalk? We can easily find out by adding some dilute hydrochloric acid. If it does not effervesce it cannot be chalk.

We wish to examine this gas given off when chalk is acted on by dilute acids. For this purpose it is necessary to prepare gas jars full of it. The gas is carbon dioxide.

PREPARATION OF CARBON DIOXIDE

Expt. 67. Fit up an apparatus as in Fig. 46. In the flask place some marble chippings. These give off carbon dioxide when acted on by dilute acids in the same way that chalk does. We could use chalk for this purpose but the effervescence would be so great that the froth would overflow into the delivery tube. Cover the chippings

with water. Pour down the thistle funnel concentrated hydrochloric acid. When this meets the water it will become dilute acid. Carbon dioxide is evolved and escapes from the flask by the delivery tube. It cannot leave by going up the funnel because the bottom of the latter is under the dilute acid. Collect several jars of the gas over water.

Dilute sulphuric acid is not used with marble because in a very short time it forms an insoluble film of calcium sulphate round the chippings, thus preventing the acid coming in contact with the rest of the marble.

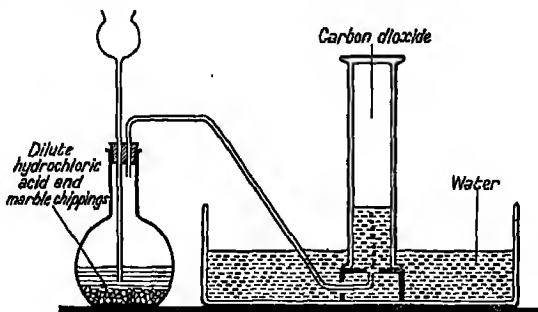


FIG. 46. The preparation of carbon dioxide.

PROPERTIES OF CARBON DIOXIDE

Which of these do you already know from its preparation and collection? It is a colourless, odourless gas, and is slightly soluble in water but not enough to prevent its being collected over water.

Expt. 68. 1. Put a lighted splint in the gas. It goes out and the gas does not burn.

2. Into another jar of the gas pour some clear lime-water. It turns milky.

3. Into a third jar of the gas pour blue litmus solution. It turns red.

4. Try to burn other substances in the gas as you did with oxygen. None will burn except magnesium. In this case the white solid magnesium oxide is formed. In addition a black solid will be noticed on the side of the jar. This is carbon. As magnesium is an element, it cannot contain either carbon or oxygen. Therefore carbon dioxide is a compound of both these elements.

5. Try to pour the gas from one jar to another as if it were water. Do it slowly. Fig. 47 will show you how to hold the jars. By means of lime-water, test for the presence of carbon dioxide in the jar into which you have attempted to pour the gas. What does this experiment show about the density of the gas compared with that of air? Remember that before the carbon dioxide can enter the bottom jar, it must push the air out. The gas must be denser than air.

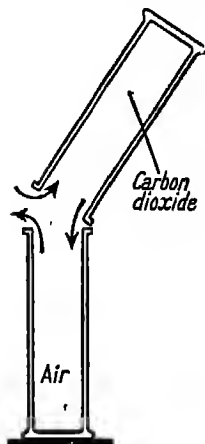


FIG. 47. Pouring carbon dioxide.

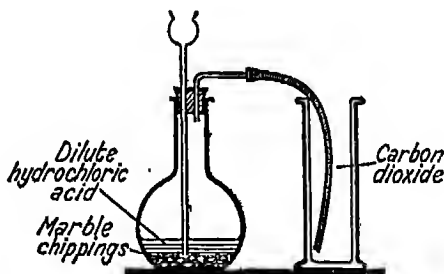


FIG. 48. Collection by downward delivery.

Instead of collecting carbon dioxide over water we can collect it by *downward delivery*, or, as some people prefer to call it, 'upward displacement of air'. To do this the apparatus should be arranged as in Fig. 48. The delivery tube should reach the bottom of the jar, and the gas entering there stays as low as possible while the air above it rises. If the delivery tube did not reach the bottom, the carbon dioxide would mix with the air. This does happen to some slight extent even with the tube reaching the bottom of the jar. Place a lighted splint at the mouth of the jar to see when it is full. The light is extinguished when the jar is full of the gas.

Carbon dioxide is not usually considered a poisonous gas but it does act as a poison if air containing a high percentage of it is breathed. When it is made in the laboratory in the ordinary way no precautions need be taken against any poisonous effect.

ABSORPTION OF CARBON DIOXIDE BY CAUSTIC SODA AND CAUSTIC POTASH

Expt. 69. Collect some carbon dioxide over mercury in a tube. Note the height of the mercury column. Insert a small piece of solid caustic soda (or caustic potash) under the mercury at the bottom of the column. The solid, being less dense than the mercury, rises to the top of the mercury column and thus comes into contact with the carbon dioxide. Note the rise of the mercury in the tube as the carbon dioxide is absorbed by the caustic soda.

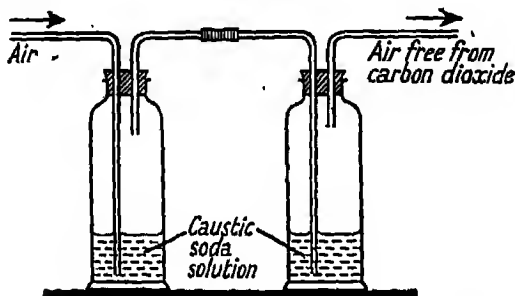


FIG. 49. To remove carbon dioxide from the air.

When we study acids and alkalis later we shall understand what happens when carbon dioxide is absorbed by caustic soda and caustic potash. Meanwhile, we may note that we have a method of removing carbon dioxide from the air. If air is passed through a wash-bottle (Fig. 49) of caustic potash or caustic soda, the carbon dioxide is absorbed but the oxygen and nitrogen pass through. This method may be used in Experiment 62 and the carbon dioxide removed before the oxygen. We then obtain nitrogen free from carbon dioxide. We shall have to use this method often in our future experiments.

USES OF CARBON DIOXIDE

1. Fire extinguishers (Fig. 50)

There are many substances which, when treated with dilute acids, give off carbon dioxide. They are called carbonates and

bicarbonates. In fire extinguishers such a substance is placed in a container, and acid is placed in another container in such a position that when the acid container is broken the acid flows on to the carbonate. It is so arranged that when the knob is struck a plunger breaks the acid container, and the acid flows on to the carbonate. There is a sudden evolution of carbon dioxide which escapes with great force through the nozzle. The stream of gas and liquid containing dissolved carbon dioxide is directed on to the fire. The extinguisher must be recharged with acid and carbonate before it can be used again.

Water will not put out burning petrol or oil but may spread the fire since some of the water may turn to steam and scatter the burning liquid. Fire engines carry a special kind of extinguisher which produces a 'foam', bubbles filled with carbon dioxide. This forms a blanket of carbon dioxide over the burning liquid.

2. 'Dry snow'

Carbon dioxide is a gas, but by the application of pressure and making the gas very cold it is possible to condense the gas to a liquid and then to freeze the liquid to a solid. This solid carbon dioxide is known as 'Dry snow' or 'Carbonic acid snow', or 'Electric ice'. It is a white solid and can be handled without danger so long as it is not pressed between the fingers, otherwise very painful sores may be formed. When left in the air at the ordinary temperature, it changes to gaseous carbon dioxide without passing through the liquid state. It can be produced quite cheaply and is in common use for keeping food cold. Solid carbon dioxide is used by modern ice-cream vendors to prevent ice-cream melting. The solid carbon dioxide should not come into contact with the food. It is also used by surgeons for freezing out warts and moles. The 'Dry snow' should not be handled with a metal spoon, but by a wooden or horn spoon (Ch. XXVI).



FIG. 50. A hand fire extinguisher.

3. Mineral waters and soda-water

Remove the stopper from a mineral water bottle and watch what happens. Bubbles of gas rise from all over the liquid and leave it at the surface. The gas is carbon dioxide. Carbon dioxide is soluble in water, but much more can be dissolved if it is forced in under pressure. When the pressure is reduced by removing the stopper, the whole of the gas no longer dissolves and some of it comes out of solution. Water charged with carbon dioxide tastes 'sharp' and is refreshing. Soda-water is carbon dioxide dissolved in water under pressure. It also contains a little bicarbonate of soda in solution. Mineral



FIG. 51. A sparklet bulb.

waters contain, in addition to the dissolved carbon dioxide, a certain amount of colouring and flavouring matter.

In soda-water syphons the pressure of the gas is sufficient to force liquid out when the lever is depressed. The liquid effervesces owing to the reduction of pressure and consequent evolution of gas from the water. It is possible to buy syphons which can be charged in the home from a small iron bulb ('sparklet') containing liquid carbon dioxide (Fig. 51). The bulb is pierced and the reduction of pressure in the bulb causes the liquid to evaporate and the gas to dissolve in the water under pressure. Carbon dioxide is commonly used in this way and no one is ever poisoned by it.

4. Baking powder

This consists (usually) of sodium bicarbonate and 'cream of tartar'. These two substances, when brought together under suitable conditions of warmth and moisture, give off carbon dioxide. If this occurs in the dough, it puffs it up, that is, the dough 'rises'. Sodium bicarbonate (bicarbonate of soda, baking soda) is often used by itself for this purpose. It is mixed with the dough, and when this is put into the oven the heat causes the sodium bicarbonate to decompose into sodium carbonate, water, and carbon dioxide.

5. The 'rising' of bread by the use of yeast

The yeast one buys at the grocer's shop consists of large numbers of a microscopic plant. Yeast is a fungus, and fungi do not obtain their nourishment like green plants (Ch. XLIV). When yeast is put into dough and kept in a warm place it begins to feed at the expense of the dough and one of the products formed is carbon dioxide. This causes the dough to 'rise'.

THE ACTION OF HEAT ON CHALK

Expt. 70. Put some powdered chalk (or precipitated chalk) in a muffle furnace and heat strongly for half an hour. When the furnace is cool again, remove what is left and examine it. Compare it with chalk. Is it chalk? How can you find out? It does not look different from chalk. Try the action of water on the substance, adding a little at a time. Does it dissolve? Does the water get hot? Is steam given off? If it is soluble in water it cannot be very soluble because we do not notice that any appreciable quantity has disappeared. Shake up some of the substance with water, allow to settle, and decant. Evaporate some of the decanted liquid to dryness. Is anything left? What does this tell us about the solubility of the substance? It is slightly soluble in water. Test the solution with red litmus paper. It is turned blue. The substance is evidently not chalk for that is insoluble in water. It is called quicklime.

Add dilute hydrochloric acid to the quicklime. There is no effervescence but the water may boil from the heat of the reaction. (If all the chalk has not been converted into quicklime there will be an effervescence.)

There are other substances which, when heated strongly, yield quicklime: e.g. marble, limestone, Iceland spar, shells (of oysters, cockles, mussels, snails), egg shells, coral, and pearls. They do so because they are really all different forms of the same substance, the chemical name for which is calcium carbonate. They are not all pure calcium carbonate, but they consist very largely of that substance. Calcium carbonate when heated yields quicklime (the chemical name for which is calcium oxide) and carbon dioxide. We did not notice the evolution of carbon dioxide when we heated chalk in a muffle furnace, but by a suitable arrangement the gas can be collected.

Calcium carbonate = Calcium oxide + Carbon dioxide.

MANUFACTURE OF QUICKLIME

Quicklime is in great demand, especially by farmers, for putting on the land (Ch. XLVII), and by builders for mortar and plaster. Great quantities are

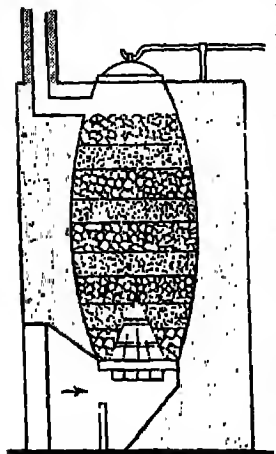


FIG. 52. A lime kiln.

The kiln is charged with limestone and coal. Chalk is used instead of limestone if the kiln is in a chalk district. The coal burns, supplying the heat necessary for the decomposition of the limestone. The ashes and lime are raked out at the bottom, while fresh charges of coal and limestone are put in at the top. Thus the process is continuous. In modern kilns the carbon dioxide is collected and used in other chemical processes. The quicklime thus obtained contains as an impurity the ash from the coal. This does not matter for most purposes, but the large lumps

of quicklime are picked out by hand. 'Hand-picked' lime is free from coal ash. It is a little dearer than the other.

LARGE-SCALE MANUFACTURE OF CARBON DIOXIDE

As stated in the preceding paragraph, carbon dioxide is obtained on a large scale as a by-product in the manufacture of quicklime.

Carbon dioxide is also obtained commercially as a by-product in brewing. We have already mentioned that yeast is used by the baker in order to make bread rise. The brewer also uses yeast (brewer's yeast) to make alcoholic beverages such as beer and whisky. Both these processes depend upon the action of the yeast plant which grows in a medium containing sugar. One of the products of this activity is carbon dioxide. This is washed, dried, and then pumped into cylinders.

QUICKLIME, SLAKED LIME, MILK OF LIME, LIME-WATER

For the further study of lime it is best to procure a lump of quicklime and carry out the operations in a bucket.

Expt. 71. Put some fresh quicklime in a dry bucket. Let water fall drop by drop slowly on to the quicklime. Note what happens. Does the lime become wet? What happens to the water? Why does adding water make the lime hot? Where does this heat come from? What change is there in the appearance of the lime? Add more water slowly until you have a dry powder.

This substance is called slaked lime. The quicklime has absorbed as much water as it could without becoming wet. Where has the water gone? The heat generated suggests that a chemical action has taken place. The quicklime has combined with the water to form a new compound, slaked lime, the chemical name of which is calcium hydroxide.

Calcium oxide + Water = Calcium hydroxide.

Expt. 72. Continue to add water to the slaked lime in the bucket. It now becomes wet. Stir with a stick. This liquid is often called milk of lime. Allow the milk of lime to stand for a few hours and decant the clear liquid from the top.

It is a solution of calcium hydroxide in water, commonly called lime-water. The substance left in the bucket after decanting is slaked lime which has not dissolved, because there was not enough water to dissolve all of it. This milk of lime is often used for whitewash. A little size should be added, to make it stick better to the wall, and a little blue colouring matter should be added otherwise it will dry a faint yellow instead of white. Lime-water is used in medicine chiefly in infant's food, for bone formation. It is also used in the laboratory for many purposes, one of which is testing for carbon dioxide. Milk of lime is a suspension of solid calcium hydroxide in a saturated solution of calcium hydroxide in water. Although lime-water is a saturated solution, it is very dilute because calcium hydroxide is not very soluble in water.

The builder manufactures slaked lime on a large scale so that he can use it for making mortar. You should take an opportunity of watching this process for yourself. The quicklime is

placed in a very large rectangular wooden trough and sprayed with water, enough being added to make a very thin milk of lime. This is then run off through a sliding partition in the trough into a sand pit, where the milk of lime sets on cooling to a thick paste which can be handled with a spade.

Mortar is made by mixing clean sand with about one-third its weight of slaked lime. Mortar sets when it loses water, partly by evaporation, and partly by the absorption of some of it by the dry bricks. In the course of many years a film of calcium carbonate appears on the mortar. This is formed by the interaction of the lime with the carbon dioxide of the air.

The gardener also uses slaked lime for 'liming' the soil. This is to neutralize the acids in the soil which tend to make the ground sour and unfit for growing plants. It is also mixed with clay soils to make them lighter and more workable (Ch. XLVII).

Cement is prepared by strongly heating a mixture of limestone (or chalk) and clay. The product is then ground to a fine powder. Cement mixed with sand, gravel, and water sets to form a hard solid mass known as *concrete*.

THE ACTION OF CARBON DIOXIDE ON LIME-WATER

Expt. 73. By means of a delivery tube pass carbon dioxide for some time through clear lime-water in a test-tube. The lime-water turns milky. What causes this?

The liquid is a suspension of tiny particles of a white solid. What is this substance? We can make a guess at the answer to this question if we remember what lime-water is. It is calcium hydroxide dissolved in water, and calcium hydroxide is a compound of calcium oxide and water. Calcium oxide was obtained by causing calcium carbonate to give off its carbon dioxide. It seems possible that the white particles causing the milkiness are particles of calcium carbonate.

Expt. 74. To the milky liquid add dilute hydrochloric acid. The milkiness disappears and there is an effervescence.

This also indicates that the white substance may be calcium carbonate. We have not proved it by our experiments, but other experiments prove that it is calcium carbonate.



II. Stalactite and stalagmite formations in Smuggler's Hole
at Buckfastleigh, Devon

Calcium hydroxide + Carbon dioxide = Calcium carbonate.

Expt. 75. Pass more carbon dioxide through clear lime-water for a long time. It goes milky at first, but soon clears again.

Now calcium carbonate is insoluble in water, so the calcium carbonate must have been changed into something which is soluble in water, otherwise the liquid would not have cleared. The soluble substance formed is called calcium bicarbonate. It is a compound of calcium carbonate, water, and carbon dioxide.

Calcium carbonate + Water + Carbon dioxide =
Calcium bicarbonate.

Expt. 76. Boil the solution of calcium bicarbonate you obtained in the last experiment.

Calcium bicarbonate exists usually in solution. On boiling, carbon dioxide is given off and calcium carbonate is precipitated, so we cannot evaporate the solution to dryness and obtain calcium bicarbonate because the latter is decomposed by heat into calcium carbonate, water, and carbon dioxide.

Calcium bicarbonate = Calcium carbonate + Water +
Carbon dioxide.

CALCIUM CARBONATE IN NATURE

Calcium carbonate, which occurs in enormous quantities, is widely distributed throughout the world. Although differing in physical properties, chalk, limestone, and marble are all forms of calcium carbonate. Whole mountain ranges consist of limestone; chalk beds of great thickness occur in many countries; and marble is the chief rock of some districts. Also calcium carbonate occurs in the sea, and most soils contain some of it in varying quantity according to the district. Limestone and marble have been formed from chalk.

Another form of calcium carbonate is known as 'Iceland spar', so named because it was first found in Iceland. It is found in the form of transparent crystals, and is used for making certain optical instruments. An object viewed through these crystals appears double, the phenomenon being known as 'double refraction' (Ch. XXXIII).

The chalk deposits were originally formed in the sea. Protozoa called *foraminifera* secrete tiny shells of calcium carbonate, the material for which they obtain from the sea, the calcium from soluble calcium compounds being combined with the dissolved carbon dioxide. When they die they fall to the bottom of the ocean, and thus a deposit of slime, or ooze, as it is called, is formed on the ocean bed. Gradually a hard layer of chalk is formed. Upheavals of the sea bed in the past have resulted in the chalk becoming part of the dry land. This process of chalk ooze formation is still going on to-day. If possible you should examine prepared slides of *foraminifera* from chalk under the microscope (Fig. 45).

Coral found in tropical seas is made in much the same way from the skeletons of the coral polyp. This is an animal closely related to the sea anemone. Coral reefs hundreds of miles long have been formed in this way.

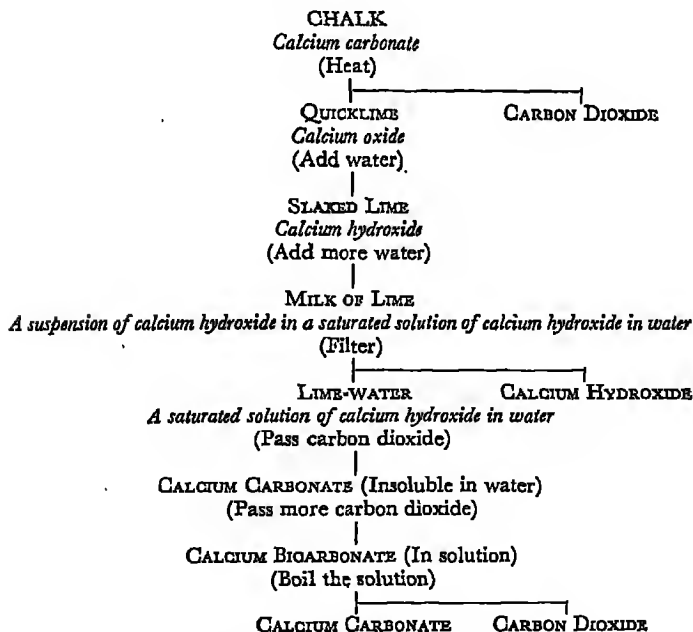
Calcium carbonate also forms the chief part of the shells of molluscs, such as oysters, mussels, snails, &c. The pearl, obtained from the pearl oyster, is also composed largely of calcium carbonate. If a grain of sand, or other foreign body, gets into the shell of the oyster, the irritation set up causes the oyster to secrete layers over the sand grain, forming a pearl. The egg-shells of birds also consist mainly of calcium carbonate. The bird secretes this substance from a gland in the oviduct and the egg becomes coated with it as it passes down the duct.

Water free from dissolved carbon dioxide does not dissolve calcium carbonate, but rain-water and indeed all water which has been in contact with the air for a time contains carbon dioxide dissolved from the air. Such water coming in contact with calcium carbonate changes it to soluble calcium bicarbonate. Thus, water flowing through a limestone or chalk district will contain calcium bicarbonate. If this water drips into a cave or underground cavern, some of the carbon dioxide escapes, changing some calcium bicarbonate to insoluble calcium carbonate. This is left as a deposit where the drop of water gave off its carbon dioxide. In the course of ages, a spike of calcium carbonate shaped like an icicle hangs from the roof, and a column rises from the floor underneath, which

received the fallen drops. The deposit hanging from the roof is called a *stalactite*, that rising from the floor is called a *stalagmite*. Sometimes a stalactite and a stalagmite join, and a column is formed. Some of these caves present a wonderful sight when lit up by torches or electric light. Well-known ones occur in the Cheddar Gorge, in Yorkshire, and in Derbyshire, and there is a very fine one near Wells.

It will be obvious from the preceding paragraph that carbon dioxide will be set free into the air. This is only one of the ways in which the atmosphere obtains its carbon dioxide. In later chapters we shall discuss other methods, and also the importance of carbon dioxide in the life of a green plant.

SUMMARY



(See p. 170 for equations dealing with these reactions.)

QUESTIONS

1. Describe simple experiments which illustrate the fact that (1) air occupies space, (2) air has weight.

State clearly your reasons for believing that (1) air exerts a pressure, (2) this pressure acts in all directions.

2. State clearly why the pressure of the air diminishes as we ascend a high mountain.

3. What value can be attached to the words 'Rain', 'Change', 'Dry', 'Fair', 'Very dry' seen on some barometers? Discuss the use of the barometer in weather forecasting.

4. Draw a labelled diagram of an aneroid barometer showing clearly its construction. In a few sentences describe how it measures the pressure of the atmosphere. Why is this type used as an altimeter? What are the limitations of this instrument when used as an altimeter?

5. State briefly but clearly (with the aid of a diagram) how the pressure of the air is applied in using one of the following: (1) the bicycle pump, (2) a self-filling fountain-pen, (3) a garden syringe.

6. Describe, with the aid of a labelled diagram, the working of a lift-pump (suction pump) stating clearly how the pressure of the atmosphere is applied.

7. Draw a labelled diagram of a force pump. State with reasons what happens (1) on the first up-stroke, (2) on the first down-stroke. What disadvantage has this type of pump and how is the construction of a modern pump modified to overcome this disadvantage?

8. Describe what can be noticed when the following elements are heated in the air: (a) magnesium, (b) copper, (c) lead, (d) sulphur, (e) charcoal.

9. State briefly and clearly your reasons for believing that some part of the air is used when elements are burned in it.

Magnesium, heated in the air, increases in weight; when carbon is similarly heated it apparently disappears. How do you account for this?

10. State clearly why air is regarded as a mixture of gases and not a compound. What are the gases in the atmosphere and what is the approximate amount of each?

11. How did Priestley first obtain the gas which has since been called oxygen? Who gave it this name and why? Is it a suitable name for this gas?

12. Name three substances which give off oxygen when heated. Choose one of them and describe what you observe when it is heated.

13. Describe the burning of either (a) sulphur or (b) carbon in oxygen. When water is shaken up with the resulting gas and blue litmus solution added, the latter turns red. Account for this.

14. What is an oxide? Give one difference between the oxide of a metal and that of a non-metal. What chemical process goes on during burning?

15. State the conditions under which iron rusts. What chemical process takes place? Is there any heat change, if so, what? What practical methods are adopted for preventing iron from rusting? State why each method is effective.

16. How would you show that there is carbon dioxide in the atmosphere? How does it get into the atmosphere and how is it taken out by natural agencies?

17. Describe the appearance of some natural chalk. How does it occur in nature?

Describe the action of dilute (a) hydrochloric acid, (b) nitric acid, (c) sulphuric acid, on chalk. How does (c) differ from (a) and (b)?

18. State briefly, without experimental detail, how a sample of air may be obtained free from carbon dioxide.

Explain how carbon dioxide is used in (a) fire extinguishers, (b) refrigeration, (c) mineral waters, (d) cooking. In what forms can you buy carbon dioxide?

19. In what forms does calcium carbonate occur in nature? Starting with calcium carbonate, how would you obtain slaked lime? What are the uses of lime (quick and slaked)? How would you distinguish chalk from lime?

20. Describe and explain the action of carbon dioxide on lime-water. What happens when a solution of calcium bicarbonate is heated?

What is the action of rain-water on rock containing calcium carbonate? What effect has this on the water? What are stalactites and stalagmites? Explain their formation.

A. Describe, with a diagram, the construction of a mercury barometer. What does it measure? How may a mercury barometer be used to determine the approximate height of a mountain? [C.W.B.]

V

ANIMALS IN RELATION TO AIR RESPIRATION

OURSELVES AND THE AIR

WE know that we are very uncomfortable, not to say distressed, if for any reason we are deprived of air for a short time. We can 'hold our breath', and even stay under water, but not for long. It is common knowledge that people and other animals deprived of air for any length of time die. We are usually unconscious of breathing, but when we run or climb a hill, we become conscious that we are breathing more quickly than usual. Apparently we need more air when we are doing physical work than when we are sitting still.

Expt. 77. Sit down and count the number of times you take in air in one minute. Now run about until you are panting; then sit down and count the number of respirations per minute.

Why do we need air? Why do we need more air when we are exerting ourselves than when we are sitting down? Do we use the whole of the air, or is there some special part of it we use?

INSPIRED AND EXPIRED AIR COMPARED

Expt. 78. Arrange an apparatus as shown in Fig. 53. The two wash-bottles contain lime-water, and the connexions are so arranged that when a person breathes (with his mouth) through the tube *A*, inspired air comes from the outside, bubbles through the lime-water in *B*, and enters the mouth afterwards, while expired air passes through the lime-water in *C* and then into the open air. Study the connexions carefully and see that this is so. With the mouth breathe through *A* for a long time and note what happens in the wash-bottles. The lime-water in *C* turns milky before that in *B*.

The lime-water in *C* has been turned milky by the expired air, that in *B* by the inspired air, that is, the ordinary air. There must be much more carbon dioxide in expired air than in ordinary air. Where has this extra carbon dioxide come from?

An answer to this question is suggested when we know that expired air is poorer in oxygen than ordinary air. Experiments show that expired air contains about 4.5 per cent. less oxygen than ordinary air, and about 5 per cent. more carbon dioxide. What kind of a chemical action does this suggest is taking place in the body? Oxygen is being used to oxidize carbon which must be in the body.

Expt. 79. Breathe on the dry surface of a beaker containing cold water. What happens?

Expired air contains more moisture than ordinary air. The moisture does not exist as liquid water, but as water vapour. This condenses on cold surfaces.

Expt. 80. Breathe on the bulb of a thermometer.

Expired air is warmer than inspired air. If a number of people are kept in a closed room for a few hours, the air becomes warmer and contains a greater percentage of moisture and carbon dioxide, and a smaller percentage of oxygen. The windows become covered with moisture. It is uncomfortable to sit in such a room, chiefly because of the temperature and the water vapour. The increase of carbon dioxide and the decrease of oxygen contribute to this discomfort.

It is remarkable how the human body can accommodate itself to a decrease in the oxygen supply. People can ascend to great heights in aeroplanes where the decrease in the pressure of the atmosphere means a smaller oxygen supply in each inspiration. They do not suffer much discomfort so long as the change is gradual. There is, of course, a limit to the height to which one can ascend and pilots who fly aeroplanes at a great height use an apparatus for increasing the oxygen supply. The climbers of Mount Everest have not only existed, but climbed, with a very restricted oxygen supply, but they found it necessary

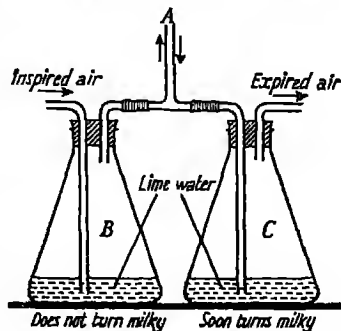


FIG. 53.

to stop for a day or two at various heights until their bodies became used to breathing in a rarefied atmosphere. On the later stages of the attempt some of them carried oxygen, but some people have said that it is possible that the extra oxygen supply did not compensate for the extra weight of the apparatus to be carried.

ANIMALS AND RESPIRATION

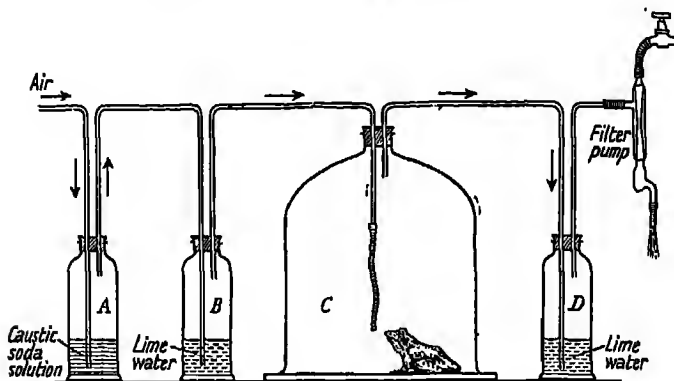


FIG. 54. Carbon dioxide is given out when a frog respire.

Expt. 81. To show that carbon dioxide is produced when animals respire. Fix up the apparatus as shown in Fig. 54. See that all the joints are tight before commencing the experiment. Air entering the lime-water in *B* is free from carbon dioxide because it has passed through the caustic potash in *A*. *C* contains the animal, e.g. a frog, an earthworm, a beetle, &c. The lime-water in *D* soon becomes cloudy and this means that carbon dioxide has entered the apparatus somewhere after the air passed *B*. It can only have been produced by the animal in *C*.

Expt. 82. To show that oxygen is absorbed during respiration. Fix up an apparatus as shown in Fig. 55. The animal is placed in flask *A* which is surrounded by a bath of water to keep a constant temperature. The tube *B* contains lumps of caustic potash to absorb any carbon dioxide produced by the animal. The coloured water rises in limb *C* of the manometer showing that oxygen has been used by the animal, converted into carbon dioxide, and absorbed by the caustic potash.

Another similar apparatus without the animal would show that the rise in *C* could not be attributed to change of volume of the air in *A* due to temperature changes.

All animals require oxygen for respiration, and in the process liberate carbon dioxide as a waste product. If oxygen is absorbed and carbon dioxide is given out during respiration, there is a net loss of carbon, which is shown by Experiment 83.

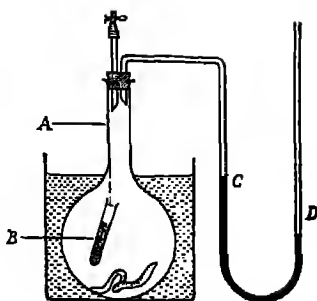


FIG. 55. To show that oxygen is absorbed during respiration.

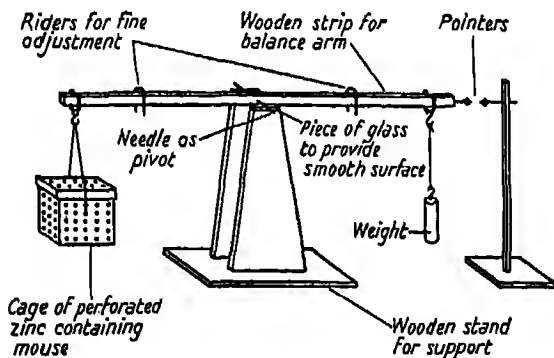


FIG. 56.

Expt. 83. To show the loss of weight through respiration. Fix up the apparatus as shown in Fig. 56. A long strip of wood is pivoted on a stand to act as a balance. A small cage made of perforated zinc, containing a mouse, is suspended at one end and counter-poised with weights at the other, the balance being accurately adjusted by means of a rider. It will be found that the mouse gradually loses weight.

Expt. 84. Obtain two pieces of wide glass tubing (glass lamp chimneys are ideal) fitted at the ends with metal cylinders, with caps, as shown in Fig. 57, and containing solid caustic potash. The tubes should be as nearly as possible the same weight and size and should

contain the same weight of caustic potash. In one tube place a mouse. Support the tubes at the ends of the beam of the balance and adjust the balance. It will now be found that the mouse apparently increases in weight. Can you explain this? Remember that the mouse is continually taking in oxygen and forming carbon dioxide. The second tube is used to cancel out the increase in weight due to absorption of carbon dioxide from the air outside.

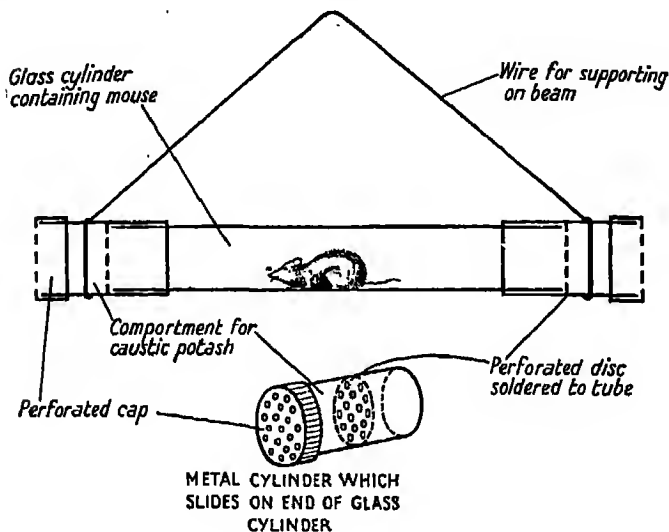


FIG. 57.

Many of the lower animals (e.g. the earthworm) respire through the skin and often have no other form of respiration. For this reason their skins are moist. Every part of the animal's body needs oxygen and every cell is supplied with it by diffusion and gives up carbon dioxide and water by the same means. This process is much too slow for large animals, for they need a constant and more rapid supply of oxygen. Again, in most of the higher animals the skin has often to serve as a protection to the animal, and consequently special respiratory surfaces are formed, e.g. *lungs* and *gills*. It is now necessary to

bring the oxygen to these surfaces, so we find definite breathing movements for this purpose.

In order to understand how air is taken in and how it is expelled by human beings we shall find it helpful to study the breathing apparatus of the rabbit, which closely resembles our own; we can compare this with that of the frog which is in some ways simpler. Let us study the frog first.

RESPIRATION IN THE FROG

Watch a frog in an aquarium. When it is at rest out of water the nostrils can be observed at the top of the head. Because of the position of the nostrils it is possible for a frog to respire air while almost the whole of its body is submerged. Note carefully the opening and closing of the nostrils and the movements of the under side of the mouth cavity (*buccal cavity*). For the greater part of the time when a frog is resting the nostrils are open and there is a steady up and down movement of the bottom of the buccal cavity. At intervals (of about a minute usually, but varying considerably according to the conditions prevailing) the nostrils close, the bottom of the buccal cavity is lowered and then raised, and there is a pronounced movement of the flanks, as if air were being taken inside.

Watch a frog under water, and time its stay there. Are there any breathing movements to be noted when it is submerged?

A frog can respire in three ways: (1) through its skin, (2) through the lining of its mouth, and (3) by means of its lungs. Let us consider each of these in turn.

RESPIRATION OF THE FROG THROUGH ITS SKIN

For this to be possible the skin must be moist, thin, and well supplied with blood-vessels. In order to reach the blood-vessels, the oxygen must first dissolve in the moisture of the skin and then be diffused through the skin. If the skin were tough the rate of diffusion would be too slow. This method of respiration is used when the frog is under water, and during its

winter sleep at which time it is frequently under water or buried in mud. The frog is always respiring through its skin to some extent, however, so long as the skin is moist.

When oxygen passes through the frog's skin it passes through the walls of some very tiny blood-vessels called *capillaries*, which form a network all through the skin. These capillaries contain blood, one of the functions of which is to carry the oxygen to all parts of the body and to bring back the carbon dioxide so that it can be passed out of the body. In the same way that oxygen passes through the walls of the capillaries to reach the blood, the carbon dioxide leaves the blood, passes through the walls of the capillaries, through the moist skin, and so dissolves in the water or escapes into the air.

BLOOD AND ITS CIRCULATION

In man and many other animals the blood circulates in what is known as a 'closed system' pumped round by the heart. This was first proved by WILLIAM HARVEY who was born in the reign of Elizabeth, was physician to the court of Charles I, and died when Cromwell was Protector. Before Harvey's time it was known that the blood moved in the body, but there was no clear realization of the fact that the heart pumped the blood out through the *arteries*, and that after passing through networks of capillaries it returned to the heart through the *veins*. Many people thought that the blood flowed to and fro, but others came very near to the truth in their speculations.

Harvey lived to see his discovery acknowledged but he never saw blood circulating, because the microscope had not been invented at the time of his death (1657). The circulation of the blood was first observed by MALPIGHI in 1661.

This discovery was of the first importance, but the role of the blood in respiration and nutrition could not be understood until the discovery of oxygen was made and oxidation was understood. This did not occur until much later (p. 58).

The blood consists of a colourless liquid known as *plasma*, containing, among other things, living cells in suspension. Some of these are coloured red and so give the blood the appearance of being red throughout. Viewed under the micro-

scope, however, it is easy to see that the red colour comes only from some of the cells.

Expt. 85. Take a small drop of frog's blood (there is no need to kill a frog specially; wait until you are doing a dissection of a frog for other purposes) and place it on a glass slide which has been very carefully cleaned. Cover with a very clean cover-glass. No air bubbles must be allowed to remain, and the blood must not run out from under the cover-glass. Examine under the high power. Do the same with a drop of your own blood. Obtain it by pricking the finger

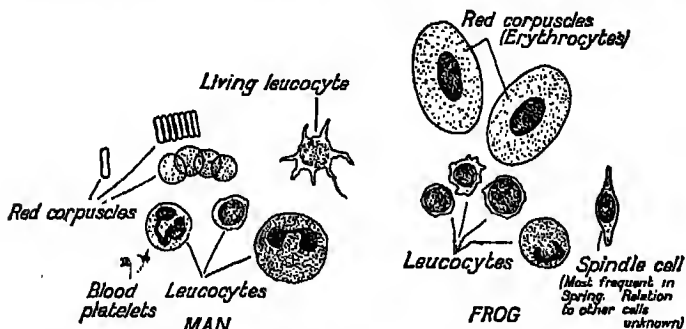


FIG. 58. Some elements of human and frog's blood.

with a needle which has been previously held in a flame until it is red hot, and then allowed to cool. (This is to sterilize the needle to avoid infection.) Examine also prepared slides of the blood of the frog and human blood. Compare what you see with Fig. 58. Note the differences between frog's blood and human blood.

The red cells, called *red corpuscles*, are round in man and oval in the frog. In the latter you may distinguish the nucleus, but it is absent from the red corpuscles of man and other mammals (i.e. animals which have hair on their bodies and suckle their young). There are also present *white corpuscles*, which are nucleated both in the frog and man. The white corpuscles are very irregular in shape, and many of them change their shape from time to time. The corpuscles concerned with respiration are the red ones, so for the present we shall confine our attention to them.

The red colouring matter is called *haemoglobin*. It is a very

complex substance. Its most important property is that it is capable of combining with oxygen very easily, and forming a new compound, *oxyhaemoglobin*. This is a very unstable compound, that is, it is easily decomposed into oxygen and haemoglobin. The blood is thus enabled to carry round about forty times as much oxygen as it would if oxygen were merely dissolved in the same amount of water.

Haemoglobin combined with oxygen is red, but when it comes in contact with anything that does not contain oxygen or will combine with oxygen, the haemoglobin gives up its oxygen and turns purple in colour. In the case of the frog, the oxygen combines with the haemoglobin of the blood in the capillaries and is taken by the blood to all parts of the body, where it oxidizes the carbon of the tissues or of the food in the tissues to carbon dioxide. This is brought back to the capillaries and is given up by the blood which then combines with more oxygen.

The circulation of the blood can easily be observed in the tail of the tadpole. Place a tadpole on a slide (or in a watch-glass) in plenty of water. It will lie there quite comfortably with its tail flat on the slide. If a slide can be obtained with a depression in it so much the better, as the tadpole's body will lie in the depression in water while the tail will lie flat in a film of water on the flat of the slide. Use the low power of the microscope. The red corpuscles can easily be seen streaming through the capillaries.

It is possible to demonstrate the circulation of the blood in the skin between the toes of an adult frog. The advantage of this method is that it can be used during seasons when a tadpole cannot be obtained, but the tadpole method is very much easier.

RESPIRATION OF THE FROG THROUGH THE MUCOUS MEMBRANE OF THE MOUTH

The mouth of the frog is kept shut but the nostrils are kept open and air is drawn into the mouth cavity (buccal cavity) by the lowering of the floor of the mouth. This causes an increase in volume of the mouth cavity and air enters to fill the space. The lining of the mouth cavity (the *mucous membrane*) is well supplied

with capillaries and there is an exchange of oxygen and carbon dioxide between the blood and the air in the mouth. The air is then forced out by the raising of the floor of the mouth cavity. The process is then repeated and fresh air is drawn into the mouth. Periodically this process is interrupted by the lung breathing method described below.

RESPIRATION OF THE FROG BY MEANS OF ITS LUNGS

Watch, or perform yourself, a dissection of the frog to show the lungs. Proceed as follows:

Put some cotton-wool in the bottom chamber of an empty desiccator. Pour on the wool a little chloroform; separate the two chambers by gauze and place the frog in the upper chamber. Put on the lid, but occasionally raise it to allow some air to enter. A mixture of chloroform vapour and air will not cause the frog any distress. When the frog appears unconscious leave the lid on all the time so that the frog will breathe chloroform vapour alone. Leave for at least twenty minutes after all signs of life have disappeared.

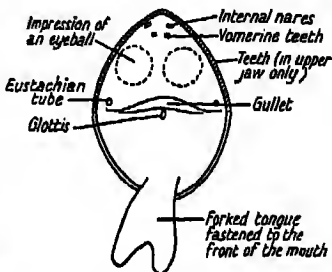


FIG. 59. The opened mouth of a frog.

Wash the dead frog in running water; open the mouth as wide as possible and examine the back portion, called the *pharynx*. There are two openings at the back of the pharynx, the *gullet*, which leads to the stomach, and the *glottis*, which leads to the lungs. The gullet is easily seen. To find the glottis look for a prominence in front of the gullet and feel on the prominence for a little slit. This is the glottis (Fig. 59). Note that it can be opened and closed. We must now see where the glottis leads to.

Lay the frog on its back on the weighted cork of a dissecting dish containing water. Pin the frog down by five pins, one through each of the hands and feet, and one through the tip of the upper jaw (Fig. 60(a)).

Lift the loose skin at *A* in the figure and cut it with the scissors. Cut the skin forward to the lower jaw and then backwards. Continue along each leg and along the arms. Separate the skin from the underlying tissue with the scissors and pin the skin back out of the way.

Before opening the body it is necessary to ligature the anterior abdominal vein, the position of which is shown in Fig. 60(b). Proceed as follows: Pinch the abdominal wall in the position shown in the

figure and make a small cut with the scissors on each side of the vein. Take care not to puncture the vein or damage the tissues underneath. Push the small scissors or forceps through one incision, under the vein, and out at the other incision. Take hold of a double thread with the points of the scissors or forceps and pull the thread through, under the vein to the other side. Cut the thread so that you now have two threads. Tie each thread separately on a double knot, leaving a space between the two ligatures. You may now cut the vein between the two threads and there will be no bleeding.

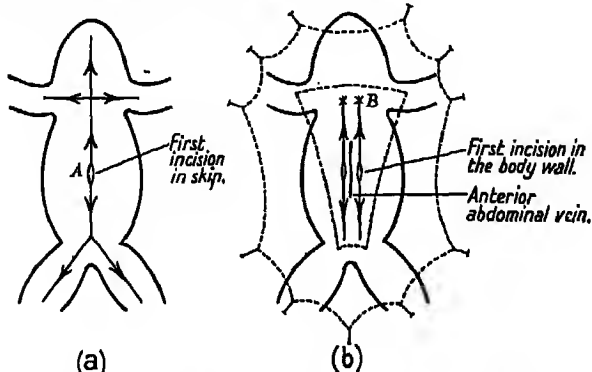


FIG. 60. The frog: (a) First cuts. (b) Abdominal vein.

Now cut through the muscles of the body wall along the lines shown in Fig. 60 (b). Keep the point of the scissors pressed upwards all the time to prevent damage to the organs lying in the body cavity. Pin back the body wall as you open it out. With strong scissors cut through the pectoral girdle in the positions shown in the figure (B). With forceps remove the portion of the girdle that is now free, loosening it from the tissues with fine scissors. Remove the pins from the hands and pull them gently sideways as far apart as possible. Pin them in their new positions.

Most of the organs will now be visible. Identify them with the help of Fig. 61. We are concerned at present with the lungs and heart for these are employed in respiration. Before you cut anything now, be sure you know what you are cutting.

Cut away the liver. Cut through the oesophagus leading from the pharynx and remove it out of the way. Find the lungs and heart and probe them very gently. Wash the whole frog in water, and get everything clean round the lungs. Look for any connexion between the heart and the lungs. Use a lens if necessary and be very careful not to damage anything as you move the heart and lungs with your seeker.

Remove the lungs by cutting as near to the glottis as possible. Wash the lungs in water and place them in a watch-glass. Examine them, using a simple microscope where the light comes upward through the lungs and then through the lens to your eye. Move the

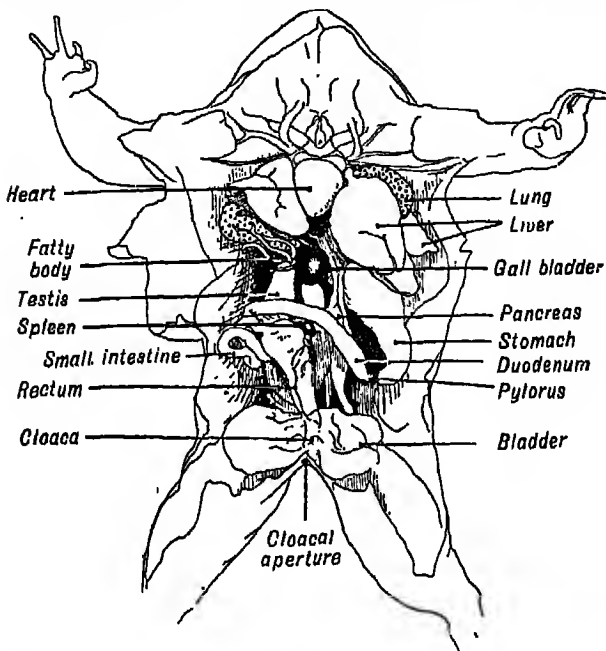


FIG. 61. The frog: internal organs.

lungs about on the watch-glass and find out all you can. Read the following description and then return to your examination.

The lungs are a pair of oval bags lying in the body cavity (Fig. 62A). They are connected by two very short air-tubes (*bronchi*) to the larynx and thence to the glottis. They have spongy and elastic walls thrown into slight folds on the inside. This folding gives a much greater area of contact with air inside the lungs. The pulmonary artery branches near the top of the lungs, one branch going to the top of each lung, branches again

into smaller arteries, and after continued branching becomes a net-work of capillaries. These unite into small veins that come together as the pulmonary vein which leaves the lungs at the top.

When the frog breathes by means of its lungs it closes the

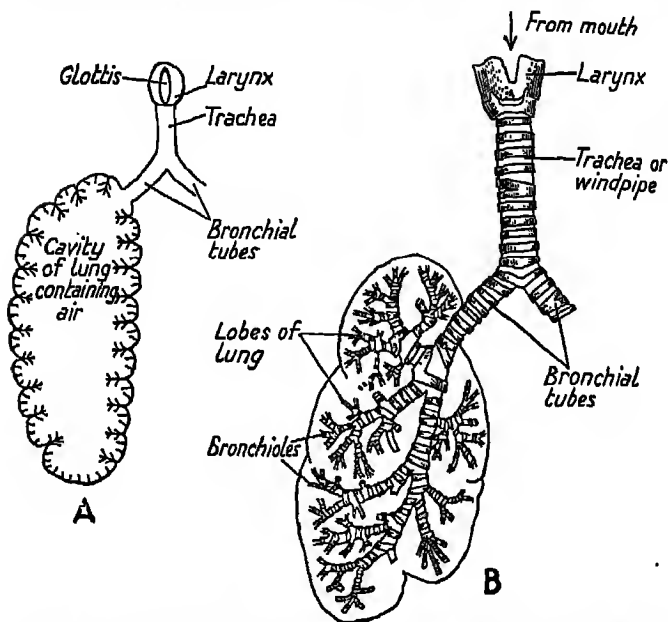


FIG. 62. Diagrams showing the structure of lungs and bronchial tubes in (A) amphibian, e.g. frog (somewhat enlarged); and in (B) a mammal, e.g. rabbit, man (somewhat reduced).

nostrils and depresses the floor of the buccal cavity. The glottis is open; thus air enters the mouth from the lungs. This air will have had part of the oxygen removed and will contain a higher percentage of carbon dioxide than ordinary air. The air from the lungs mixes with the air already in the mouth. The floor of the buccal cavity is now raised and, the nostrils still being closed, the compressed air has only one path, that is via the glottis, so air is forced into the lungs. The

glottis is now closed. The air is retained for some time in the lungs during which time the movements accompanying 'mouth' respiration may continue. The lungs never receive a full charge of ordinary air, but a mixture of ordinary air and air which has been in the lungs before. When the air is in the lungs there is an exchange of gases between the blood in the capillaries and the air in contact with them.

The blood flows from the heart through the pulmonary artery to the lung capillaries and contains little or no oxygen but much carbon dioxide. The latter is given up to the air in the lungs while oxygen from the lungs passes through the walls of the capillaries and combines with the haemoglobin of the blood. This is carried by the pulmonary vein to the heart which pumps it to all parts of the body. There the oxygen is taken up by the tissues in exchange for the carbon dioxide which is absorbed by the blood and eventually reaches the lungs.

This process of breathing by the lungs is one in which the mouth cavity acts as a force pump. The mouth is kept shut, the lips making it air-tight, otherwise expiration and inspiration would be impossible. The frog would die of asphyxia if its mouth were artificially kept open for a considerable time.

RESPIRATION OF THE RABBIT

We shall consider the rabbit because, like ourselves, it breathes only by lungs, and these are very much like our own.

From a dealer procure a rabbit which has been killed without injury to the lungs or the cavity in which they lie and has not been opened. Proceed as follows to examine the lungs and heart:

1. Fasten the body to the dissecting board with the ventral (i.e. belly) surface upwards. The body should be stretched taut and pinned through the feet.

2. Pull up the skin over the abdomen and snick transversely through it with the scissors. Be careful not to damage the body wall. Continue the cut both forwards and backwards along the middle line of the body, releasing the skin from the body wall from time to time by using the back of a scalpel. In this way remove the skin from the ventral surface and the neck. Pin the skin back out of the way.

3. Open the abdomen by a median longitudinal and a transverse cut just behind the ribs. Do not carry the longitudinal cut any farther forward than is necessary for seeing the liver and the stomach (Fig. 63).

The liver is a large, solid, reddish organ overlying the stomach and attached at the anterior (forward) end to the *diaphragm*. The latter is a thin partition separating the cavity of the thorax from the abdominal

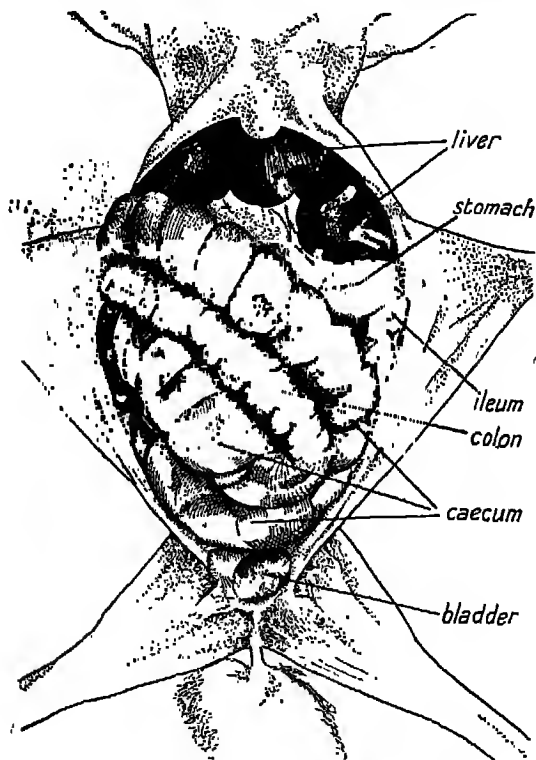


FIG. 63. The rabbit: internal organs.

cavity which is much larger. The stomach is smooth and bluish-white; it is partially hidden by the liver.

4. Find the oesophagus, which leads into the stomach. Remove the liver a little at a time to make certain that the diaphragm is not damaged in the process. Remove the stomach and the intestines.

5. You will now be able to examine the surface of the diaphragm as seen from the abdominal region. Feel it and note that it is stretched tightly and is concave.

6. Remove the muscles of the breast, thus exposing the breast bone and the ribs. Be careful not to puncture the thorax in doing this.

7. Note again the position of the diaphragm on the abdominal side. Pierce with a scalpel the wall of the thorax between the fourth and fifth ribs counting from the anterior end. Now examine the diaphragm again. What has happened?

8. Repeat this on the other side, and again examine the diaphragm. Has anything further happened?

9. With scissors remove a small part of the wall of the thorax

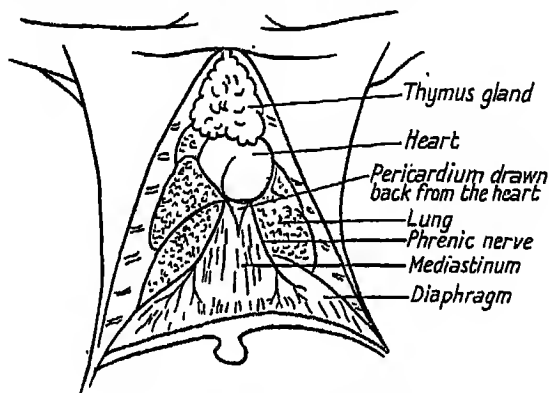


FIG. 64. The rabbit: thoracic cavity.

anterior to the fifth rib. The part removed should include part of the breast bone and a little on each side of it. Now that you can see what you are doing, enlarge the opening just made but be careful not to do any damage to the organs in the cavity. Do not cut anything until you know what you are cutting. Examine the cavity, using a blunt seeker to push the organs gently aside (Fig. 64). Note the membrane that divides the right from the left side of the cavity. Note the heart, enclosed in a transparent membrane, the *pericardium*. Gently remove the pericardium by cutting with the scissors. Examine the lungs, which are pink and spongy. They occupy the greater part of the cavity. Note that they are free except at the anterior end, where they are connected with (1) the two *bronchi* which branch from the wind-pipe, (2) the blood-vessels of the heart.

10. Dissect aside the muscles of the neck and expose the wind-pipe (*trachea*). Gently detach it from the surrounding tissue. Cut it across and insert a tube in the part below the cut, and tie the trachea firmly to it. Blow down the tube. The lungs become inflated. Note how

they fill the cavity of the thorax. Allow the air to escape from the tube. The lungs collapse again.

11. Remove the heart, taking care not to damage the lungs.

12. Remove the lungs together with the trachea.

13. Examine the lungs. Wash them in water. They float. The left lung is divided into two lobes and the right into four. Again blow down the tube, thus inflating the lungs. Note that they collapse when the blowing is discontinued. The lungs are spongy, elastic, and air-tight. Identify the branches of the pulmonary artery which conveys the blood from the heart to the lungs, and the pulmonary vein which carries the oxygenated blood from the lungs to the heart (Fig. 66).

14. Cut a piece off the lung and note the escape of air bubbles.

15. Tease a little of the lung out and examine under the simple microscope.

16. Remove the diaphragm by cutting across the ribs to which the diaphragm is attached and freeing it from the oesophagus and the muscles of the back by the scalpel point. Stretch it out on the board and examine it. Note the muscular part round the circumference.

THE BREATHING MOVEMENTS OF THE RABBIT

Let us try to reproduce artificially the conditions in the thoracic cavity when the rabbit is breathing.

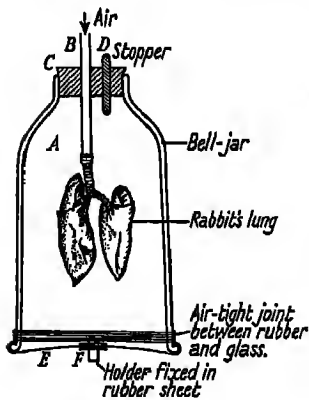


Fig. 65.

Expt. 86. Fit up an apparatus as shown in Fig. 65. *A* is a bell-jar fitted with a two-holed cork *C*. Through one hole passes an open tube *B* which is pushed in the trachea of the lungs of a rabbit, and fastened by strong thin string. Through the second hole is passed a glass rod *D*, to act as a stopper. *E* is a sheet of rubber stretched tightly and fastened to the flange of the bell-jar by string and made air-tight. *F* is an attachment to the rubber by which it may be handled. Remove *D* and press the rubber sheet upwards so that it is concave towards the outside. While

it is in this position insert the plug *D*. It now represents the conditions in the thorax when the diaphragm is concave seen from the abdominal cavity.

Take hold of *F* and pull the rubber sheet down. This causes an

increase in volume in the bell-jar and a consequent reduction in the air pressure. Air therefore enters the lungs through *B*. Push the sheet up. Air leaves the lungs.

This is part of what happens in the thoracic cavity of the rabbit. As the diaphragm moves backwards and forwards, operated by muscles which are controlled by nerves, there is a decrease, followed

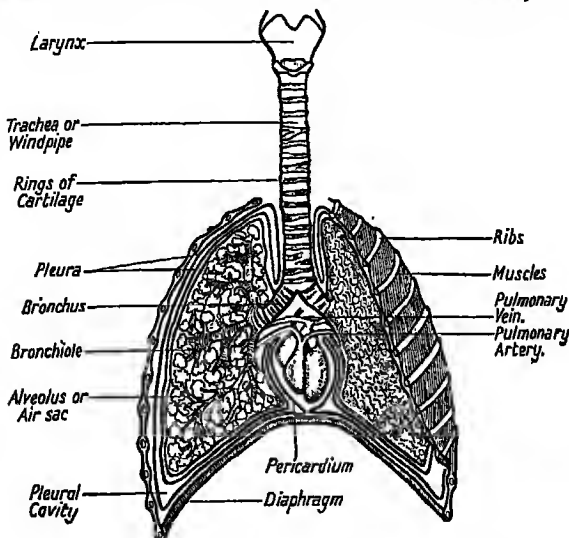


FIG. 66. Lungs and heart of mammal (diagrammatic).

by an increase, of pressure in the cavity which causes the lungs to be alternately filled and partially emptied of air. (A toy balloon may be used if the lungs of a rabbit are not available.)

There is also another method by which the thoracic cavity is enlarged. The chest wall is supported by ribs fastened to the back bone dorsally (i.e. upper surface of the animal), and all except the last three (floating ribs) to the breast bone ventrally (under-surface of the animal). Sets of muscles between the ribs pull the ribs upwards and downwards as required. When the ribs move upwards, the breast bone is pushed forward, thus enlarging the thoracic cavity. The cavity is diminished when the ribs move downwards.

A complete 'breath' consists of an inspiration, a pause, and an expiration. Air is inspired by increasing the size of the thoracic cavity by raising the ribs and lowering the diaphragm. The air pressure inside the lungs causes them to expand and fill the enlarged thoracic cavity. This diminishes the air pressure in the lungs so that air is now 'sucked' in via the nose, throat, and trachea until the pressure in the lungs equals the atmospheric pressure. In expiration, the ribs move downwards and the diaphragm domes upwards. The volume of the lungs therefore diminishes and air is breathed out until the pressure in the lungs is again equal to atmospheric pressure.

A rabbit shot through the chest would have its thoracic wall punctured and so the lungs would collapse.

BREATHING IN MAN

The rate of breathing in normal man is about sixteen times per minute. It is higher in children and during exercise. During exercise the muscles produce more carbon dioxide. The amount of carbon dioxide in the blood controls the rate of breathing. The control is exercised by a part of the brain. When the blood containing extra carbon dioxide produced by exercise reaches the brain, the rate of breathing is increased.

When we breathe out, we do not empty the lungs at each breath, for in ordinary breathing we take in and breathe out about 500 c.c. of air, whereas the lungs would actually take about seven or eight times as much.

In artificial respiration pressure on the back causes pressure on the abdomen, thus forcing the diaphragm to dome upwards. In addition it compresses the chest and so air is expelled. The pressure is then relaxed and air is drawn into the lungs. In other words, an attempt is made to provide the normal movements by rhythmic pressure on the back.

In certain illnesses the chest and other muscles or nerve centres concerned with breathing fail to function, and so the patient is placed in an 'iron lung' from which only his head protrudes. In some later forms only the thoracic region is enclosed. An air-tight connexion is made round the neck and air is withdrawn from the box surrounding him. Air rushes in

through the mouth and nose to inflate the lungs since a partial vacuum exists outside the patient, i.e. within the enclosure. The reverse process causes the lungs to be deflated. Artificial respiration is thus continued over a long period, for weeks or months. The patient can eat and sleep while in the lung. For short periods of treatment a more portable form of 'lungs' is used fitting only over the chest of the patient.

A recent development in 'lungs' is the respirator room where doctors and nurses have ready access to the bodies of patients.

In each nostril of the nose are 'scroll' bones (so named because they resemble a scroll of paper) covered by a delicate layer of tissue which secretes mucus and contains many minute blood-vessels. The incoming air is therefore moistened, so preventing the drying up of the surface of the lungs. It is also warmed by the blood, thus preventing chilling of the lungs. The mucus, aided by the hairs in the nostrils, collect the many particles of dust, spores, &c., which are present in the air and which would otherwise clog the delicate respiratory surface of the lung. From the above it is obvious why one should always breathe through the nose except when swimming.

A good supply of fresh air is necessary for health. There is no difficulty about this when we are out of doors, but many people have to spend much time in rooms, mines, and underground railways. All of us have to spend many hours in a bedroom asleep so that the building-up processes can outpace the breaking down. Under all these conditions a good oxygen supply is necessary. (See under ventilation, Ch. XXVI.)

THE LUNGS OF THE RABBIT

These are much more efficient than those of the frog (Figs. 62 B and 66). The air enters by the glottis, which is protected by the epiglottis, which closes the opening when food is being swallowed. This prevents any food going down the trachea instead of the gullet. From the glottis the air passes the voice-box (larynx) and thence into the trachea which branches into two *bronchi* one on each side of the lungs. The trachea and its branches are lined with *cilia*, cells having tiny whips of protoplasm which beat upwards to drive any particles of dust, &c.,

back towards the throat. The bronchi subdivide into branches one for each lobe of the lung. The branches repeatedly subdivide in the lung until each of the smallest branches ends in a microscopic air-sac (*alveolus*). The lung is a mass of these air-sacs (*alveoli*) and this accounts for the fact that the lungs appear spongy and float on water. (They are often called 'lights'.)

The pulmonary artery enters the lung at the top and divides into smaller arteries which repeatedly subdivide until they form a capillary net-work on the walls of the alveoli. The capillaries unite to form veins and these join together to become the pulmonary vein which leaves the lung at the top. The pulmonary artery brings to the capillaries from the heart blood which has no oxygen but has much carbon dioxide. It is called de-oxygenated blood and is not red, but purple.

The walls of the capillaries are thin and the carbon dioxide passes from the blood through the walls into the alveoli, while oxygen passes from the alveoli into the blood where it combines with the haemoglobin. The blood which passes from the lungs to the heart by the pulmonary vein is, therefore, oxygenated blood. (The pulmonary artery is the only artery which carries de-oxygenated blood; and the pulmonary vein the only vein to carry oxygenated blood. A vessel carrying blood *from* the heart is called an ARTERY; a vessel carrying blood *to* the heart is called a VEIN.)

As in the case of the frog, the heart pumps the oxygenated blood to all parts of the body and the gaseous exchange between the blood and the living cells takes place through the capillary walls, the blood losing oxygen and receiving carbon dioxide. The de-oxygenated blood then goes to the heart whence it is pumped to the lungs to be oxygenated.

RESPIRATION IN MAN COMPARED WITH THAT OF THE RABBIT AND THE FROG

Frogs, rabbits, and human beings all belong to a very large class of animals called back-boned animals (*vertebrates*). The class includes also birds and fishes. In this class lung breathing is not universal. Rabbits and human beings belong to a smaller, but still large, class of animals called *mammals*. All mammals

have a diaphragm; the lungs of a rabbit may be taken as a type of mammalian lungs. The frog has no diaphragm, nor are there alveoli in the lung, though it is much folded. The mammalian lung is much more efficient than that of the frog because there is a much greater area over which gaseous exchange can take place. In man there are probably some 700,000,000 alveoli giving a respiratory surface with an area of 60 to 100 square yards. Whereas air is forced into the lungs of the frog, the mouth cavity acting as a force pump, in the mammal air is 'sucked' in by reduction of air pressure in the lungs. On the other hand, the frog has additional methods of respiration and respire under water. No mammal is able to breathe under water. Even the whale, which is a mammal, must come to the surface to breathe. In mammals, although the skin does not have anything like the same respiratory value, it is probable that in man something like one-fiftieth part of the carbon dioxide excreted each day is given off dissolved in the sweat of the skin. As well as excreting carbon dioxide the skin of the frog absorbs both oxygen and water, but the absorbing power of man's skin is practically negligible.

RESPIRATION OF FISHES

Let us now see how fishes respire. They are vertebrate animals but it is evident that they cannot breathe by lungs.

Watch a fish in an aquarium. It opens its mouth, takes in water, and then closes its mouth. This goes on repeatedly. We shall see that these are breathing movements.

Examine a dead mackerel or herring. Note the slits on each side of the fish. These are called gill-slits, and are openings to the gill chambers. Lift the flap (operculum) covering the gill-slit and examine the gills. Note the gill arches lying one over the other with a gill cleft between each pair opening into the pharynx (Fig. 67). Each arch bears bright-red gill filaments, a large area of gill being exposed to the water. The fish takes in water by the mouth. When the mouth closes the water is forced into the pharynx. This contracts and the water is forced through the gill clefts, then into the gill chamber, and so out through the gill-slit.

The gill filaments contain numerous blood capillaries filled with de-oxygenated blood. As the water passes the gill

filaments, the oxygen dissolved in the water combines with the haemoglobin in the blood, which gives up its carbon dioxide to the water, in which it dissolves.

The heart of the fish pumps de-oxygenated blood through the gills where it becomes oxygenated. The blood then goes to all parts of the body without first returning to the heart. This is different from the circulation in the frog and the rabbit. It does not return to the heart until it is again de-oxygenated.

Gills are adapted for extracting the oxygen dissolved in water. They cannot take oxygen from the air. A fish out of water dies for lack of oxygen; a human being in water dies for

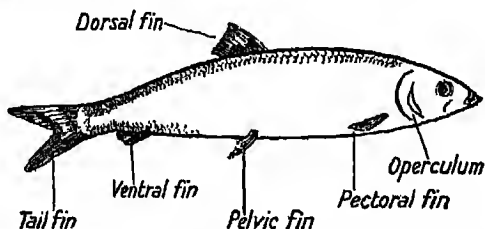


FIG. 67. The external features of a fish (herring).

the same reason. A frog seems to have made the best of both worlds. It is called an *amphibian*.

During one period of its life a frog has no lungs and respire by gills. At this stage of its development it is called a tadpole, and lives like a fish. It would die if kept out of water for long. When the tadpole first leaves the jelly it has no mouth and so internal gills, like those of the fish we have studied, are impossible. Instead it has tiny filaments projecting from its sides by which it respire. When the mouth appears the external gills disappear, and internal gills, almost like those of a fish, appear. As the frog develops, it acquires lungs as breathing organs, and the internal gills finally disappear (Ch. XLVIII).

RESPIRATION IN INSECTS

We have seen that the essential feature of respiration is that all living cells shall receive an adequate supply of oxygen and the waste carbon dioxide shall be removed from them. In

almost all large animals the blood is brought to a special respiratory organ, lung or gill, there receives oxygen, and transports it to the cells of the body which it bathes. In insects the air is taken *direct* to every part of the body by a system of branching tubes, thus avoiding the necessity of having to be

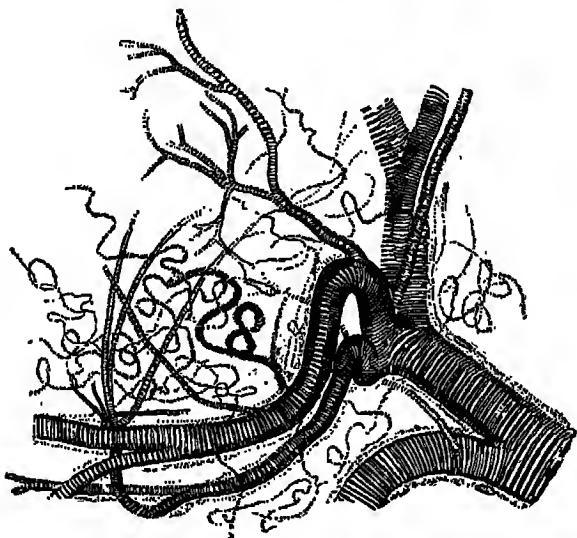


FIG. 68. Trachea.

carried by a respiratory fluid. These tubes, known as *trachea* (Fig. 68), reach the surface of the body at openings called spiracles. The large tubes are prevented from collapsing by a spiral thickening on the inside of the wall, resembling the metal wire on a garden hose. Contraction of special muscles in the wall of the abdomen causes air to be driven out of the trachea; when the muscles relax, more air enters. These movements can readily be observed on a living wasp or dragon-fly.

This method of respiration in insects is remarkably efficient, an obvious necessity when one considers the extremely active life led by such animals.

RESPIRATION IN SOME VERTEBRATE ANIMALS

<i>Method</i>	<i>Vertebrates (Back-boned animals)</i>		
	MAMMALS	AMPHIBIANS	FISHES
	Suckle their young; have hair on the body, e.g. man, rabbit.	Live in both air and water, e.g. frog.	Live in water only, e.g. cod.
By means of LUNGS	Well developed, with alveoli. Only method. Diaphragm. Ribs.	Not well developed; folded but no alveoli. No diaphragm. No ribs.	None.
GILLS	None.	None in adult. Present in tadpole stage. External gills at first, then internal gills.	Only method.
SKIN	Some excretion of carbon dioxide.	A very important method in the adult stage.	None.
MUCOUS MEMBRANE OF THE MOUTH	None.	An important method.	None.

WHAT IS THE PURPOSE OF RESPIRATION?

This question is going to lead us a long way before a satisfactory answer is possible. We have seen the connexion between respiration and oxidation; and we know that in at least one case heat is produced during respiration. Is the production of heat the purpose, or one of the purposes, of respiration? We know that human beings and many other animals keep up a temperature usually higher than that of their surroundings; but there are many animals (the frog, for example) which do not do so. Why do such animals respire?

Then there are the plants. Do they respire to produce heat? If so, what becomes of the heat? Why is carbon dioxide produced during respiration? Carbon must have been oxidized,

but where does the carbon come from? Is carbon a constituent of all living matter? It would appear so from what we know of respiration.

Is there any other product of respiration beside carbon dioxide? To all these questions we must try to find answers, and it will be necessary to learn something about the chemistry of some of the constituents of living matter. But first let us study the relations of plants to air.

QUESTIONS

1. State all the differences you know between the air inspired and that expired by a human being. Describe two experiments by which you would show two of these differences.
2. An earthworm respires through its skin. Why is this method unsuitable for human beings?
3. Describe in detail how a frog respires.
4. Who first demonstrated the circulation of the blood, and who first observed it? What part does the blood play in respiration?
5. Compare the lungs of a frog with those of a human being (or rabbit). The system of 'lung breathing' in the frog is not very efficient. How does the frog overcome the disadvantage of such poor lungs?
6. What part does the diaphragm play in the respiration of the rabbit (or man)?
7. Describe the process of artificial respiration. When should it be used and for how long?
8. What is an 'iron lung'? What is it used for and what is the principle of its action?
9. Compare the respiration of an insect (e.g. the house-fly) with that of the back-boned animals (e.g. man, fish, the frog). What common feature belongs to all?

VI

PLANTS IN RELATION TO AIR

I. RESPIRATION

We have seen that animals respire by taking in oxygen and

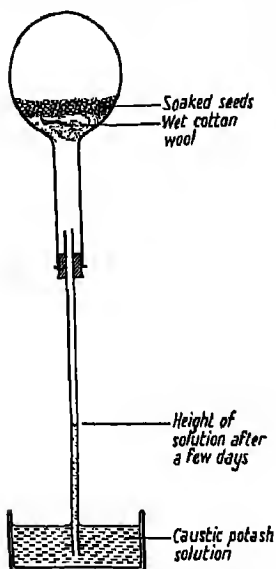


FIG. 69. To show that germinating seeds give off carbon dioxide.

Set up a similar apparatus as a control, but this time use seeds which have been killed by boiling.

Examine them after a day or two. It will be found that the caustic soda solution has risen in the tube of the first apparatus but not (or only slightly) in the control experiment.

The diminution in volume means that carbon dioxide has been absorbed by the caustic soda solution. This carbon

dioxide, and that the oxygen must reach all the living cells of the animal. Plants are living things, and we must now see if they respire in the same way. There is one obvious difference, of course. We can often see the breathing movements of animals but we cannot see any movements in plants which suggest they are respiring.

Let us perform some simple experiments which will help us to discover if plants respire.

OXYGEN AND CARBON DIOXIDE EXCHANGE

Expt. 87. Place some soaked seeds on wet cotton-wool in an inverted flask as shown in Fig. 69. The flask is fitted with a bung through which passes a piece of glass tubing. Fix up the apparatus so that the end of the

tubing is below the surface of some caustic soda (or caustic potash) solution.

Set up a similar apparatus as a control, but this time use seeds which have been killed by boiling.

Examine them after a day or two. It will be found that the caustic soda solution has risen in the tube of the first apparatus but not (or only slightly) in the control experiment.

The diminution in volume means that carbon dioxide has been absorbed by the caustic soda solution. This carbon

dioxide formed, must have taken the place of oxygen in the original air. Thus in respiration oxygen is absorbed from the air and an almost equal volume of carbon dioxide is given off. You can test this by repeating the experiment but putting the end of the tube into water instead of caustic soda.

The experiment should be repeated using flower-heads, or pieces of potato, or well-washed roots instead of the soaked seeds.

Expt. 88. Another way of showing that a plant evolves carbon dioxide is to use the apparatus in which we showed that an animal

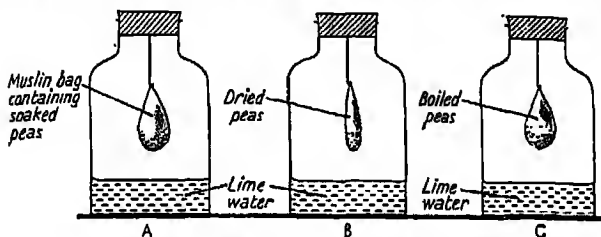


FIG. 70. Respiration of germinating peas.

gave off carbon dioxide (p. 88). In place of the animal substitute a small pot-plant. The jar containing the plant must be covered with black paper. The reason for this will be seen later.

The plant gives off carbon dioxide.

RESPIRATION OF GERMINATING SEEDS

Expt. 89. Pour some clear lime-water into three wide-mouthed jars, A, B, C. In A suspend from the cork (Fig. 70) a muslin bag of soaked peas. In B suspend a similar bag of dry peas, and in C a bag of peas which have been boiled and so killed. Watch the lime-water day by day, and note in which jar it first becomes cloudy.

The soaked peas begin to germinate and growth is vigorous. Just as we give out more carbon dioxide when we are active than when we are resting, so the peas give out more carbon dioxide when germinating than when resting. The dried peas are in the resting state and give out very little carbon dioxide. We assume that the dried peas give out some carbon dioxide

because they are alive, but the amount is so small that it does not cause any cloudiness in the lime-water. The boiled peas are dead and do not liberate any carbon dioxide until they begin to decompose, the carbon dioxide then liberated being due to the activity of bacteria and not to that of the seeds.

This experiment should be performed again using in *A* a peeled potato, in *B* an unpeeled potato, and in *C* a peeled, boiled potato. Which gives out the most carbon dioxide? Can you account for the result?

THE PRODUCTION OF HEAT DURING THE RESPIRATION OF SEEDS

Expt. 90. Put some damp cotton-wool into a vacuum flask. On to

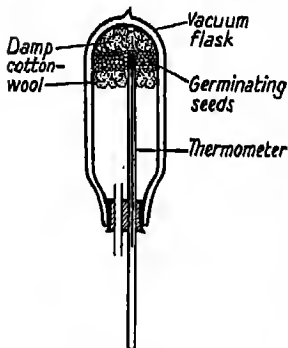


FIG. 71. Production of heat during respiration of seeds.

this drop some moist mustard seeds, and then another layer of damp cotton-wool. Bore two holes through the cork, one to receive a thermometer, and the other to receive a piece of glass tubing. Insert the cork so that the bulb of the thermometer is surrounded by the mustard seeds. The glass tube should not reach the mustard seeds. Support the flask in the inverted position shown in Fig. 71. Arrange a 'control' in which the seeds and cotton-wool are dry, but everything else the same. Place the two flasks near each other and take readings of the thermometers at least once a day.

The moist seeds germinate but the dry ones do not. The carbon dioxide produced escapes by the glass tube; it is a heavy gas and travels downwards. What do you notice about the readings you have taken? Can you account for the fact that the flask containing the germinating seeds is warmer than the other flask?

We know that when seeds germinate carbon dioxide is produced, and we now learn that heat is produced also. This reminds us very much of the burning of carbon in the air. In both cases carbon dioxide and heat are produced. In respiration, oxidation of carbon compounds takes place.

HOW A PLANT RESPIRES

Plants and animals are alike in that they both take in oxygen and give out carbon dioxide. Every living cell needs oxygen, and we saw that in those animals possessing a blood system the blood carried the oxygen from the respiratory surface to all parts of the body. There is nothing corresponding

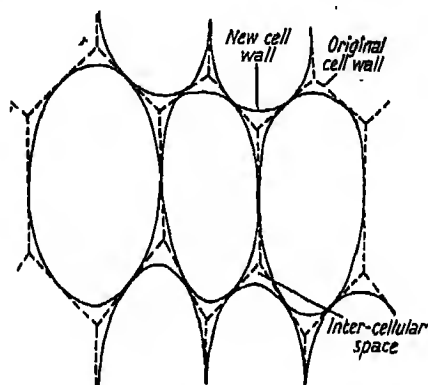


FIG. 72. The formation of intercellular spaces.

to this in the case of plants, and yet in some way or other, each living cell of a plant, no matter how deeply seated, must have oxygen. How is this effected?

When cells are first formed in a plant by the division of one cell into two, they are closely packed. The cell walls touch each other all round; but as they grow older the cell walls split apart in places, usually at the corners (Fig. 72). In time the intercellular spaces so formed make a continuous system throughout the plant. These spaces are filled with air, probably a little different in composition from that of the atmosphere.

Examine cross-sections of different parts of a plant, the root, the stem, and the leaf. Note the intercellular spaces between the cells (Figs. 11, 12).

The intercellular spaces are in communication with the

atmosphere, in the leaves and all green parts of the stem. In the skin (*epidermis*) of these parts occur the stomata. These are used for the passage of gases as well as for the passage of water vapour. The stomata are very small holes. We shall see that this is an advantage to the plant (p. 121).

Where the plant is hard and woody, there are no stomata, but the intercellular spaces are in communication with the outside atmosphere by means of lenticels.

LENTICELS

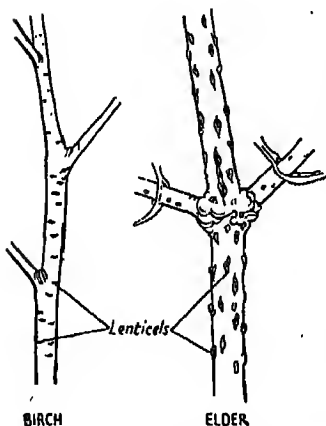


FIG. 73. Sprigs of (a) birch, (b) elder, showing lenticels.

Examine twigs of elder and birch. Look for long, narrow, transverse slits on the bark. They are very conspicuous on the white bark of the older branches of the birch (Fig. 73). These slits are called *lenticels*. Strip the cork layer from the twig and note that the lenticels are not merely on the surface, but go right through to the underlying tissues. Look for lenticels on other plants. Cut sections of elder, birch, and other plants through the lenticels and examine them. If you cannot do this, examine a prepared slide of a section through a lenticel. Compare it with Fig. 74.

Underneath the epidermis of the stem there is a ring of closely packed cork cells. Ordinary cork cells are impervious to gases and water. A lenticel is a break in this ring. Instead of the cells being closely packed, there is a mass of loosely packed cork cells through which gases can travel. Where there is a deep layer of cork, the lenticel is a long passage of loosely packed cells forming a duct. This passage is continuous with the intercellular spaces in the plant. During the winter the lenticels are closed by the formation, at the end of the season, of a thin layer of the ordinary, closely packed cork cells, so-called winter cork. During this period the plant is not growing and

respiration is reduced to very small proportions. There is, therefore, no need for lenticels. If these remained open while the plant is inactive, it is possible that bacteria causing disease might enter the plant. It is also better that the plant tissue should be protected as far as possible from the frost and cold of winter. When growth starts the following season the stem

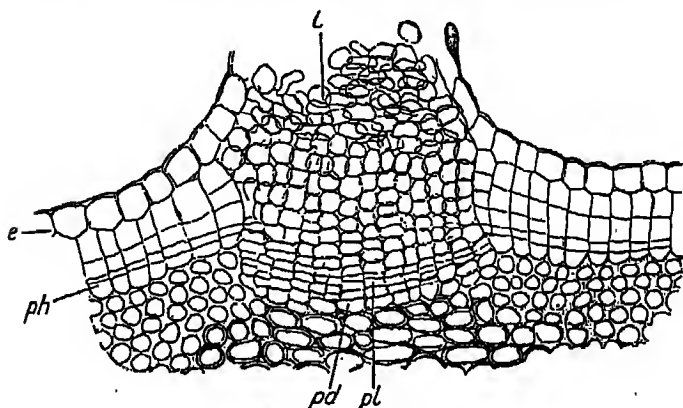


FIG. 74. A section through a lenticel.

expands, and the cork sheet is broken at these weak places so lenticels become filled with alternating zones of powdery tissue and ruptured layers of cork.

CONTINUITY OF INTERCELLULAR SPACES

Expt. 91. Place a twig of a plant which shows lenticels under very hot water. Note the bubbles of gas which come from the lenticels.

Expt. 92. Put the blade of a leaf into water and blow with the mouth through the leaf-stalk. You may see bubbles of gas coming from the surface of the leaf which has stomata. If you do not, fasten the leaf-stalk (*petiole*) to a bicycle pump by stout pressure tubing and blow air through. Bubbles will now certainly come from the stomata. This shows that there is continuity between the leaf-stalk and the stomata.

Expt. 93. Put some water into a jar, fitted with a two-holed rubber stopper. Through one hole fix the petiole of a leaf so that the end of

the petiole is in the water. Through the other hole fit a glass tube the end of which is not in the water. Using an exhaust pump fastened to the other end of the glass tube, draw air from the jar. If the apparatus (Fig. 75) has been made air-tight, bubbles of gas will be seen to leave the cut end of the petiole.

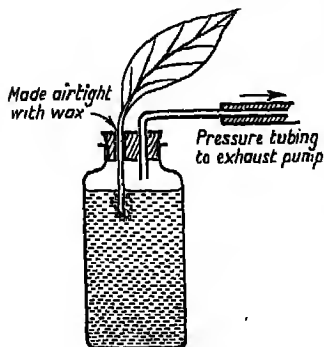


FIG. 75.

RESPIRATION OF AQUATIC PLANTS

How do plants which are submerged, or partially submerged, respire? In those plants whose leaves float on the surface of the water, e.g. the lilies and the water crowfoot, the stomata are on the upper surface of the leaf, and not, as is usual, on the under surface.

Skin off the upper epidermis of the water crowfoot and examine it with the high power of the microscope. Do the same for the lower epidermis.

Further, intercellular spaces in aquatic plants are very large.

Tease out the stem of an aquatic plant, e.g. *Elodea* (Canadian pondweed), in a little water. Examine under the microscope. You will find it difficult to cut sections of stems of water plants because the tissues are so soft, due largely to the number of intercellular spaces. Try with the stem of a lily. If you do not succeed, examine a prepared specimen (Fig. 76).

The individual cells of the water plant must depend very largely for their oxygen supply on the air in these intercellular spaces, but some air passes from solution in the water through the epidermis of the stems and leaves. The epidermis of the submerged parts of water plants is usually thin. In aerial parts the epidermis is thicker to prevent desiccation.

COMPARISON OF ANIMAL AND PLANT RESPIRATION

We have shown that respiration is one of the essential characteristics of life and takes place in every living cell whether of a plant or an animal. In both plants and animals

oxygen is consumed and carbon dioxide, among other waste products, liberated.

The plant has no special respiratory organs and there are no breathing movements. Plants are much less active than animals, and therefore do not need as much oxygen, so that the

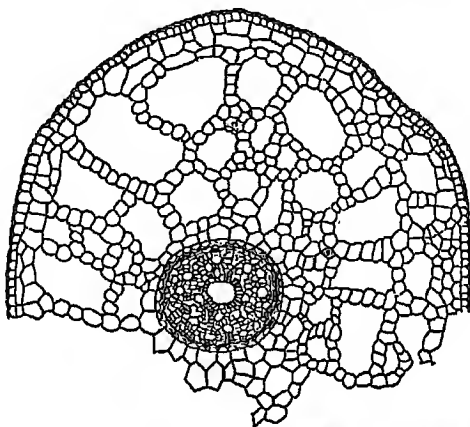


FIG. 76. Section of stem of *Potamogeton* showing air passages in the cortex.

slow process of diffusion is sufficient. Animals on the other hand are active and need a rapid and plentiful supply of oxygen.

THE DIFFUSION OF GASES

There is no definite circulation of air through the intercellular spaces of a plant, corresponding to the circulation of blood (carrying oxygen and returning with carbon dioxide) in many animals. How then does the air get changed, or is it always stagnant? To understand this we must first study the *diffusion of gases*.

If some ammonia gas is released in the corner of a room, those standing in the opposite corner are soon aware of it by its smell. Some of the gas travels quickly and soon it is spread

equally all over the room. If a jar of oxygen is placed mouth downwards over a jar of carbon dioxide, the two gases in time mix, so that oxygen and carbon dioxide are eventually equally distributed throughout the two jars. Some of the carbon

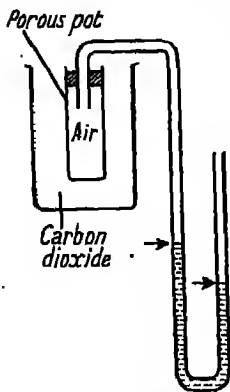


FIG. 77. Diffusion of gases.

dioxide, in spite of its greater density, rises to the jar previously occupied by the oxygen. If the jars are placed with the carbon dioxide on top and the oxygen underneath, the gases mix much more quickly, because their relative densities help. The point is, however, that even when the densities do not help, the gases mix.

We have already met diffusion in liquids (p. 29). Gases diffuse much more quickly than liquids. Compare the speed with which ammonia diffuses in a room, with the speed at which a drop of dye put in a beaker of water spreads uniformly through the water. In the latter case it may take a week. Solids

when in contact rarely diffuse, and when they do, it is usually a very slow process. Gold will diffuse into lead but it is a few years before any gold can be detected in the lead.

Gases will diffuse through porous membranes or plates. Air, for example, will diffuse through the brick walls of a room.

The rate at which a gas diffuses depends partly on its density and partly on the size of the pores in the membrane. The denser a gas, the more slowly it diffuses through a porous membrane; but the relation is not one of simple variation. The fact is known as GRAHAM'S LAW OF DIFFUSION, and is stated: 'The relative speeds of the diffusion of gases are inversely proportional to the square roots of their relative densities.'

Expt. 94. Fix a porous pot (one of the kind used in battery cells is suitable) to the end of a U-tube as shown in Fig. 77. Hold a beaker containing carbon dioxide so that the porous pot is in an atmosphere of that gas. The air diffuses out more quickly than the carbon dioxide diffuses in. There is a reduction of pressure and the coloured liquid moves upward.

The above law applies to dry gases. It has been shown that the law does not apply when the porous membrane is wet. In this case the more soluble gas diffuses more quickly; for example, carbon dioxide will diffuse more quickly than oxygen through a wet membrane, but through a dry one the rates of diffusion are in the reverse order.

It has been found that a gas diffuses much quicker through a number of very small holes than it does through a single opening of the same total area. This is very important from the point of view of plant respiration through stomata. The number of stomata on a leaf may be millions; the number on a broad bean leaf must be reckoned in hundreds of thousands. Yet the total area of the openings is very small compared with the total area of the leaf. Nevertheless, it has been calculated that the diffusion of air through the stomata of a leaf is as effective as if the whole area of the leaf had been used for that purpose.

AIR IN THE INTERCELLULAR SPACES

We now see how it may be possible for all the living cells of a plant to be in contact with the gases that are in the atmosphere. The spaces are continuous in the plant, and in communication with the outside air by means of stomata and lenticels. The gases of the atmosphere diffuse through these openings and finally reach, by diffusion, all the cells of the plant. Any gas given off by any cell of the plant, if passed into an intercellular space, can by diffusion reach the outside atmosphere. There is no certainty that it will reach the outside atmosphere, because it may enter into a chemical reaction within the plant; but there is free communication between the gases in the plant and the gases in the air outside.

The composition of the air in the intercellular spaces will be different from that of the air outside because the rates of diffusion of the gases are different, and so are their solubilities in water; but whatever its composition, it will contain all the gases of the air in some proportion or other.

QUESTIONS

1. Every living cell requires oxygen for respiration. How do plants and the higher animals differ in the ways oxygen reaches all the cells?

2. How do aquatic plants obtain their oxygen for respiration? Illustrate your answer by reference to the structure of (1) a plant similar to *Spirogyra*, and (2) the water crowfoot or *Elodea* (Canadian pondweed).

3. Draw a labelled diagram of the apparatus by which you would show that a frog gives out carbon dioxide during respiration. How would you modify the experiment to show that a green plant respire with the same result?

4. How would you show that the intercellular spaces in a plant are continuous? How are they in communication with the atmosphere?

A. Give a brief account of the respiratory system in man. In what respects does the respiration of an herbaceous plant differ from that of man? [N.J.B.]

B. Describe, with the help of sketches, the respiratory tract and lungs of a mammal, and the mechanism by which the processes of inspiration and expiration are carried out. Point out the purposes served by the various structural features you mention. [N.J.B.]

VII

PLANT RELATIONS TO AIR

2. CARBON ASSIMILATION

THE ACTION OF LIGHT ON GREEN PLANTS

IN Experiment 88 we showed that a green plant gave off carbon dioxide, but this was in the dark. We covered our plant with black paper to keep out the light. Let us now see what gas, if any, is given off by a green plant in the presence of sunlight.

Expt. 95. Put some Canadian water weed (*Elodea*), or any other water plant such as *Spirogyra* or even watercress, in a beaker of ordinary tap water. Cover it with an inverted funnel as shown in Fig. 78 and arrange an inverted test-tube full of water to collect any gas given off. Place it in diffused sunlight. *The experiment works well on a sunny day in a warm room.* Watch the bubbles of gas

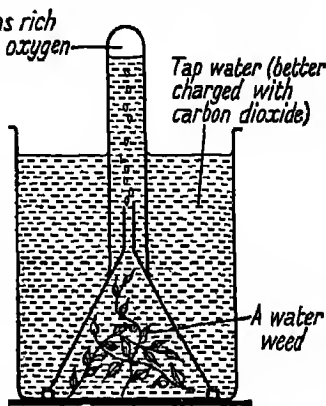


FIG. 78. A green plant gives out oxygen in the sunlight.

which rise from the plant and travel to the top of the test-tube. When there is sufficient to test, remove the test-tube and place a glowing splint in the gas. It relights the glowing splint, so the gas is either oxygen or a mixture of gases rich in oxygen. (The experiment will work better if the water is previously saturated with carbon dioxide.)

Remove the apparatus from the light and repeat the experiment in the dark. There is little or no gas given off and certainly none that will relight a glowing splint. The carbon dioxide given off in respiration all dissolves in the water.

The plant gives off oxygen in the light but not in the dark.

Expt. 96. Boil some tap water to expel the air. Repeat the above experiment with this water. Be careful that in the cooling and fitting up of the apparatus, the water does not dissolve any more air than

performed, and in a great percentage of cases the plant dies before the plant in the control, it may be taken that it is very likely that the plant dies earlier because it has been deprived of carbon dioxide. Later, a better, but more indirect, experiment will be performed to show that a plant cannot live long without carbon dioxide.

We have not yet answered the question at the head of this paragraph, but we have shown: (1) it is very likely that a plant will die in the absence of carbon dioxide; (2) if the plant does take carbon from the carbon dioxide of the air then the air left is richer in oxygen. Can we possibly find an answer to the question: Does the plant, in the presence of sunlight, take carbon from the carbon dioxide of the air? If it does, then the carbon must be in the plant in some form or other. Of course it need not be in the form of the element. Free carbon cannot be found in any part of the plant. It could be combined with something else to form a compound.

We must try to find in the plant, then, a compound of carbon. If we find this present after the plant has been in the sunlight for some time, and absent after the plant has been in the dark for some time, then it would seem that the plant does indeed take the carbon from the carbon dioxide of the air, leaving oxygen.

STARCH IN THE LEAF OF A PLANT

Expt. 99. Take a pinch of laundry starch and shake it up with water in a test-tube. It does not dissolve. Boil the water in the test-tube. Take a little of the jelly-like solution obtained, in another test-tube, and add water. To this add a solution of iodine (dissolve a little iodine in a solution of potassium iodide in water). The liquid containing the starch turns blue. Warm the solution; the colour disappears. Cool it again; the blue colour returns.

This is known as the *iodine test for starch*. Conversely it may, of course, be used as a test for iodine.

Expt. 100. To test a green leaf for the presence of starch. Kill a green leaf, e.g. geranium or nasturtium, by placing it in boiling water for a few seconds. Place the leaf in a small beaker of methylated spirits (use the colourless variety of spirits known as industrial methylated spirits) standing in a beaker of hot water. This will remove the green colouring matter (*chlorophyll*) from the leaf. When the leaf is

decolorized, wash it in water. Place it in a dish containing iodine solution. The parts containing starch will turn blue.

Unfortunately for this test, iodine stains various parts of the leaf yellow and brown, so the blue colour is masked. It looks more black than blue. You may not find starch in the first leaf you examine. Try one which has been in the sunlight all day.

WHAT IS THE INFLUENCE OF LIGHT ON THE PRODUCTION OF STARCH IN THE LEAF?

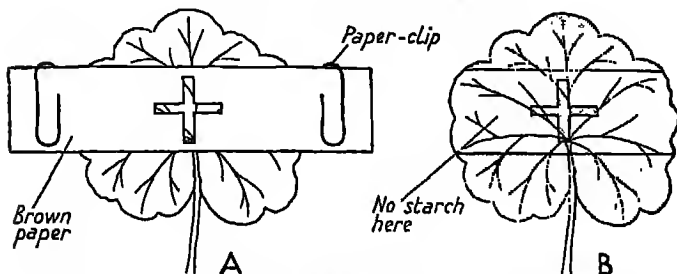


FIG. 80. Experiment to show that starch is formed only in those green cells which are exposed to light.

Expt. 101. Take a healthy plant growing in a pot. Cover one part of one leaf with a strip of black paper or tin foil kept in position by clips. (A pattern may be cut out of the paper as shown in Fig. 80.) Place the plant in diffused sunlight all day, and then examine for starch the leaf which has been partially shaded.

You will find that the uncovered part of the leaf turns blue with the iodine test, but that the covered part is brown. If you have cut out a pattern on the paper, you will find that it is reproduced on the leaf.

In the sunlight the green leaf manufactures starch; in the dark it does not. The starch is made only in that part of the leaf which has received the light.

Expt. 102. Stand the plant in a dark cupboard for two days and then test a leaf for starch. There is none. Where has the starch gone? We know that there was some there before the plant was put in the cupboard. Now there is none. Put the plant in the light again for a day and test a leaf for starch. Has more starch been made?

Starch manufactured during the daylight disappears during the night. We shall have to find out later what becomes of it.

WILL A PLANT MANUFACTURE STARCH IN THE ABSENCE
OF CARBON DIOXIDE?

Expt. 103. Take a leaf (a primrose leaf is suitable) from a plant which has been kept in a dark cupboard for two days. It should then contain no starch. Put the leaf so that part of it is in the air of a small jar containing some caustic soda solution and part of it is in the ordinary air outside. Allow the stem to dip in water so that the leaf will not die for lack of it. Arrange a control with water in the jar instead of caustic soda solution. Be sure that everything else in the control is the same. Place the experiment and the control together in diffused sunlight all day. Test both leaves for starch.

The part in the jar does not manufacture starch, the part outside does. In the control both parts of the leaf, inside and outside, manufacture starch. The part of the leaf in the jar containing caustic soda solution had no carbon dioxide, for this was absorbed by the caustic soda solution. Plants in the absence of carbon dioxide do not manufacture starch.

IS CHLOROPHYLL NECESSARY FOR THE MANUFACTURE
OF STARCH?

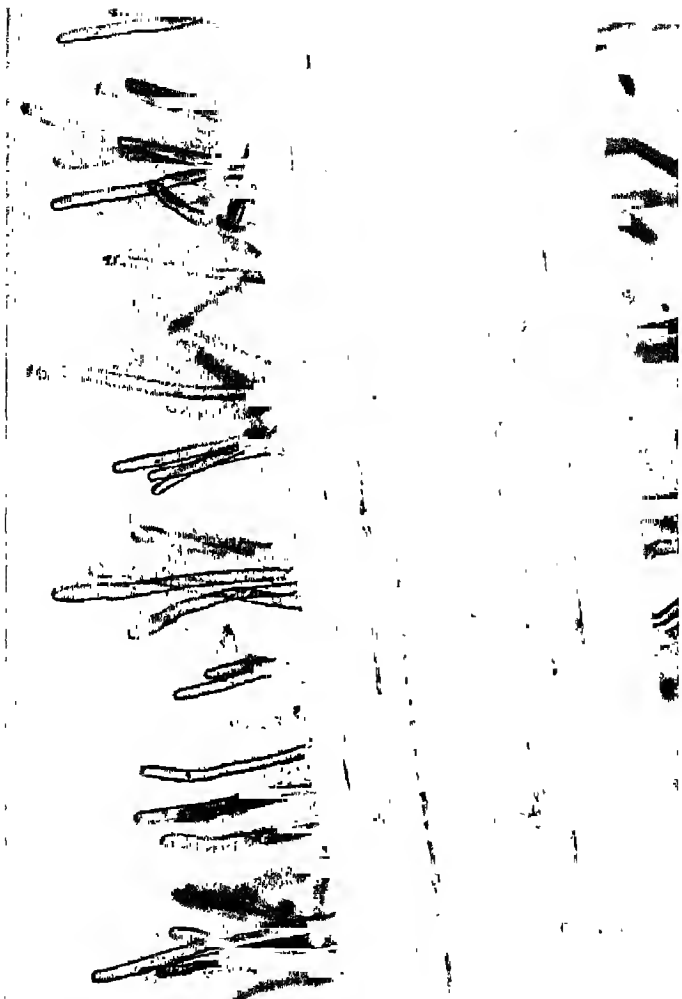
Expt. 104. Stand a geranium plant having 'variegated' leaves in the light all day, and test one leaf for starch. The pale part of the leaf shows no starch; the other part does. The pale part has no chlorophyll in it and it produces no starch.

This experiment is not conclusive because the pale part may have had some substance present which prevented the formation of starch. It has, however, been found that starch is never manufactured from carbon dioxide in any part of a plant which contains no chlorophyll. Those parts of a plant containing chlorophyll, even if they are not leaves, manufacture starch.

There are some plants, e.g. the fungi (mushroom, toadstool, &c.) which possess no chlorophyll. These are unable to manufacture starch from the carbon dioxide of the air.

THE MANUFACTURE OF SUGAR AND STARCH IN THE GREEN
PART OF A PLANT

The aim of the preceding experiments has been to determine the conditions under which starch is found in the leaf. If the same experiments are performed with leaves from certain



III. Root hairs (greatly enlarged) of Lucerne, a common fodder plant of the Pea family

plants called monocotyledons, it is found that in a number of these, e.g. those of the onion, no starch is present. Not all leaves make starch, but all leaves make sugar.

Expt. 105. Make a solution of glucose (grape sugar) and add a little Fehling's solution.* On warming, a yellow or red precipitate should be obtained. Repeat the experiment using cane sugar. No precipitate is formed. Add a few drops of dilute sulphuric or dilute hydrochloric acid to a solution of cane sugar and boil before adding Fehling's solution. A precipitate is now formed. This is because warming with acid converts the cane sugar into simpler sugars like glucose.

Expt. 106. Take a young leaf of an onion, chop it up into small pieces and warm with a little water in a basin. Decant the liquid into a test-tube, add a little Fehling's solution and boil. A reddish-brown precipitate indicates the presence of sugar. With some leaves of other plants no precipitate is formed.

We have seen that green leaves, when exposed to sunlight, contain sugar and starch. Some leaves contain only sugar, some a little starch and much sugar, others much starch and little sugar. The sugar is made before the starch. Both are classed as *carbohydrates* (p. 137), and both can be decomposed into carbon and water. The plant, in the presence of sunlight and with the aid of chlorophyll, can manufacture sugar (glucose) from carbon dioxide and water. The oxygen not being required is released. The chlorophyll uses the light for this purpose somewhat as a chemist uses the heat of a bunsen for making substances react. Sugar and starch differ in that sugar is soluble but starch is insoluble in cold water.

When the sugar is made from the carbon dioxide and water, it dissolves in the cell sap. It is probable that if the cell sap becomes too concentrated by the dissolved sugar, no more sugar is manufactured. In most plants the sugar changes into insoluble starch and is stored in the cell for a time. This is true for most plants, but it cannot be true for all, because in some

* Fehling's solution is kept in two separate bottles, from which equal parts are mixed just before use. The solutions are made up as follows:

Bottle A—Dissolve in 1 litre of water 70 gm. of copper sulphate crystals.
Bottle B—Dissolve in 1 litre of water 350 gm. of Rochelle salt and 100 gm. of caustic soda.

plants, e.g. the onion, the sugar is not changed into starch but remains in the leaves in great quantity.

Carbon assimilation, i.e. the process of combining the carbon from the carbon dioxide of the air, with water from the soil to form either sugar or starch, is sometimes called *photosynthesis*. The first part of this word draws attention to the part light plays in the process, while the second part reminds us that the process is the 'building up' of a compound which is more complex than the compounds (carbon dioxide and water) from which it is made. Both terms, carbon assimilation and photosynthesis, are in common use; both have their advantages and both have their disadvantages.

THE BALANCE OF CARBON DIOXIDE AND OXYGEN IN THE AIR

Perhaps you have been wondering if respiration goes on during periods of daylight. In respiration the plant takes in oxygen and gives out carbon dioxide. This is easily detected during the periods of darkness, because no photosynthesis is then taking place. Respiration does not cease during the day but takes place side by side with photosynthesis; so that respiration occurs all the time a plant is alive. When a plant gives out oxygen during photosynthesis, part of the oxygen is used in respiration; but there is more oxygen given out during photosynthesis than the plant can use in respiration. The carbon dioxide given out by a plant during respiration in the daytime is taken in by the plant in the process of photosynthesis. Carbon dioxide is also taken in from the air because there is not sufficient produced by the process of respiration.

It must not be supposed that the plant actually gives out carbon dioxide which is then taken in during the process of photosynthesis. No doubt the gaseous exchange takes place inside the leaf. Let us summarize these processes:

<i>Period</i>	<i>Process</i>	<i>Gases absorbed</i>	<i>Gases evolved</i>
Night-time	Respiration only	Oxygen	Carbon dioxide
Day-time	Respiration Photosynthesis	Oxygen Carbon dioxide	Carbon dioxide Oxygen

The net result of the two processes taking place during the day is that carbon dioxide is taken in and oxygen given out. It is still common to hear these facts described as follows: 'During the day a plant breathes in carbon dioxide and breathes out oxygen; while during the night a plant breathes in oxygen and breathes out carbon dioxide.' This is not only loose language but is actually wrong. A plant respire by taking in oxygen and giving out carbon dioxide all the time. It never takes in carbon dioxide in respiration; the process of photosynthesis is one of nutrition and not respiration. Another common error is not so serious but it betrays a lack of a sense of proportion. It is: 'Flowers should be removed from a sick room at night because during that period they remove oxygen from the air and give out carbon dioxide.' It is true flowers do this, but it cannot affect the patient because the amount is so small that it is inappreciable. It is good for the flowers to be removed from a warm room during the night and kept in a cool place. They will last longer, because the rate of respiration will decrease.

The amount of carbon dioxide in the air is very small compared with the total amount of the air. In 10,000 parts (by volume) of air, only three to four parts are carbon dioxide; but the total quantity of that gas must be enormous. Great as this supply is, it would soon be exhausted by plants if it were not being continually renewed. Roughly half the dry weight of a plant is carbon, and all this has been taken from the air in the form of carbon dioxide.

Carbon dioxide enters the air (1) as the result of the respiration of plants and animals including human beings, (2) during the processes of combustion, e.g. the burning of wood and coal, and the slow oxidation of matter containing carbon, and (3) by the action of bacteria in the soil (Ch. XLIV).

The oxygen removed from the air during the respiration of plants and animals is returned to the air during photosynthesis in plants. As far as can be determined the amounts of oxygen and carbon dioxide in fresh air remain almost constant.

THE LEAF AND CARBON ASSIMILATION

We learned something about the leaf when we were studying the relation of plants to water. We must examine the leaf more closely to understand the part it plays in carbon assimilation. We can learn much about the structure of leaves by examining suitable entire and fresh ones under the microscope.

Examine a small leaf from the tip of the growing shoot of the Canadian pond weed (*Elodea*). Mount the whole in water or 50 per cent. glycerine. Use first the low power and then the high power. Mount another one in water to which a little iodine solution has been added. Note the position of the blue parts and compare this specimen with that mounted in water without the iodine. Mount another leaf in caustic potash solution. This makes the leaf more transparent and some of the structures can be seen more clearly. In the same way examine other small leaves. Choose those which are very thin. The tiny leaf of the Virginian stock is suitable. Put a larger and thicker leaf between two flat pieces of potato, carrot, or elder pith, and try to cut transverse sections of the leaf. Mount in the same way as you did the small entire leaves. Examine prepared slides of sections of leaves (Fig. 11).

The skin (*epidermis*) of the leaf consists of a layer of cells the outer walls of which are thickened. The walls of most cells consist of cellulose, but the thickened walls of the epidermis are made of a fatty substance which is almost impermeable to water and air. In the epidermis occur the stomata.

The tissue in the central part of the leaf is called the *mesophyll*. The upper part of the mesophyll consists of closely packed cells, longer than they are broad, with the greatest length at right angles to the surface of the leaf. This is called the *palisade tissue*. The lower part of the mesophyll consists of cells loosely packed, with large intercellular spaces. This is called the *spongy tissue*.

The cells of the mesophyll contain grains of a green substance. These are called *chloroplasts* and consist of granules of protoplasm containing chlorophyll. The chloroplasts occur in much greater numbers in the palisade tissue than in the spongy tissue, but not in the cells of the epidermis except the GUARD cells.

The starch is formed and stored for a time in the chloroplasts, in the form of small irregularly shaped granules.

Through the mesophyll run strands of conducting tissue, the so-called 'veins' of the leaf. These are enclosed in a sheath and are continuous with the conducting vessels of the stem and root. They contain the same kinds of vessels.

The ordinary green leaf is well adapted to the function of photosynthesis. It is flat, and a large area is exposed to the light. The thickened epidermis acts as a screen which protects the chloroplasts from too much light and heat. The palisade tissue is so arranged that the effects of too much light can be counterbalanced. When the leaf is in diffused light the chloroplasts collect at the top of the long cells so as to catch all the light possible; but in strong light, the chloroplasts arrange themselves along the length of the cell. The chloroplasts are disk-shaped, and when in this position the thin end of the chloroplast is exposed to the light and not the broad area. This is most easily seen in the duckweed and moss leaves because of their thinness. They lack screening layers and are thus more sensitive.

The gaseous exchange between the plant and the air takes place through the stomata as in respiration and in transpiration. The gases diffuse into the large intercellular spaces of the spongy tissue and so come in contact with all the cells of the mesophyll. It is in these cells that the sugar is made from the carbon dioxide and water in the presence of sunlight and chlorophyll. Sugar is not the first product of this reaction, but is the first easily-detected product. When the cell sap is rich in sugar, the latter is changed into starch and stored temporarily in the chloroplasts.

CONDITIONS NECESSARY FOR THE FORMATION OF CHLOROPHYLL

Expt. 107. Put a board on a lawn and leave it for a day or two. Remove the board and examine the grass. Note the colour and the length of the grass compared with that of the uncovered grass.

Expt. 108. Compare some broad bean seedlings germinated in the dark, with others germinated in ordinary light. In each case note the colour and size of the leaves, the colour of the stem, where there is greatest growth in the stem, and the firmness of the stem.

Chlorophyll does not develop in the absence of light, but it will develop in light which is too weak for the formation of

starch. A plant grown for a long time in the dark usually has long straggling stems, almost white in colour, small yellow leaves, and a greater growth of the soft parts compared with the hard parts. The chloroplasts themselves develop in the dark but they do not contain chlorophyll. That is why the usually green stems appear almost white.

The chloroplasts of the leaf which has grown in the dark contain etiolin, which gives a yellow appearance to the leaf. A plant having this appearance through being grown in the dark is said to be *etiolated*. When an etiolated plant is placed in the light it soon develops chlorophyll and becomes green. The gardener keeps soil round the leaf-stalks of celery so that they will not develop chlorophyll because he wants them to be white. If the soil were removed from the stalks they would turn green and would not be nice to eat. The heart of lettuce is also etiolated. If a potato, which is the swollen end of an underground stem, is left in the light, it turns slightly green, and those which occasionally appear above the ground are green.

A plant grows quickly in the absence of light. This is an advantage to the plant, because the quicker it grows the sooner it is likely to reach a place where it will receive normal light. A green plant cannot live indefinitely in the dark because it cannot make sugar and must live on its reserve food supply.

Chlorophyll will not develop in the chloroplasts unless there is at least a trace of iron. This element does not enter into the composition of chlorophyll, but it appears to be essential for its formation. Ordinary water and soil contain enough iron for this purpose, and in food stores and seeds of plants there is sufficient to last the plant for a very long time. It is therefore not easy to prove that iron is essential. Sometimes it is found that a plant has the appearance of etiolation even when grown in sunlight. The addition of a little of an iron compound to the soil in which it grows often causes the plant to become green and healthy. Poor lawns are sometimes treated with sulphate of iron for this purpose.

STARCH

Starch is a very important compound and we must learn more about it.

Cut a very thin slice of potato and examine it under the microscope. Note the cell walls and the cells crowded with starch grains.

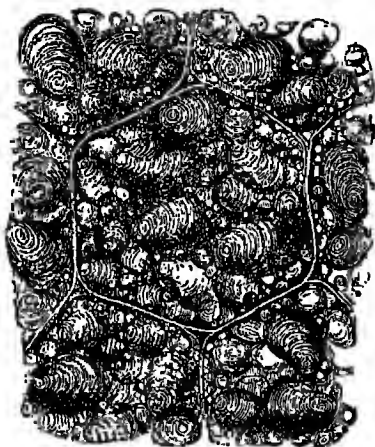


FIG. 81. Cells of potato showing starch grains, greatly magnified.

Put on it a little iodine solution. The whole section appears almost black. Study Fig. 81 and try to identify the main feature in your preparation. It will not be easy to make out the structure of the starch grains in this way, but you can extract the starch grains from the potato and examine them.

Expt. 109. To extract starch grains from the potato. Peel a raw potato and scrape it with a knife, allowing the scrapings to fall into a dish. Place the pulpy mass in a fine muslin bag. Squeeze the bag in a beaker of water. The starch grains pass through the muslin with water and after a time settle on the bottom of the beaker. Decant and wash the grains with water. (You will lose some every time, but you need very few.) Make a suspension of the remaining grains in water and add some eosin stain (or methyl green). Put some of the stained suspension on a slide, cover with a cover-glass, and examine with the high power. Repeat, using iodine solution instead of eosin. You will now be able to see the shape of the grains (Fig. 82).

They are shaped like an oyster or mussel shell. Fine striations, nearly concentric, are on the surface. These lines show where successive layers of starch have been added. Starch grains

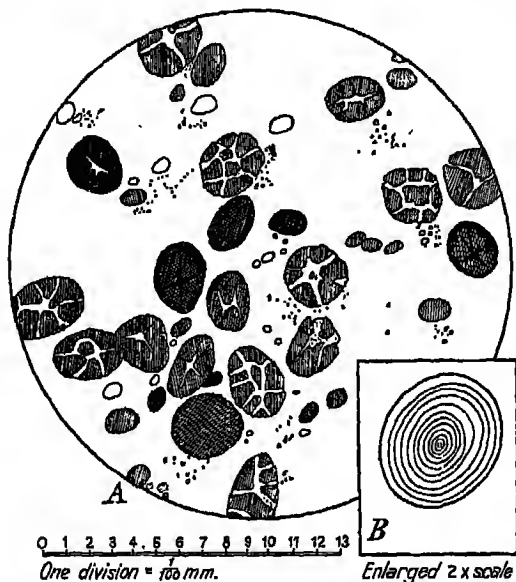


FIG. 82. Starch grains.

appear in many parts of a plant, and in most plants, but they are not all like potato starch. The grains occurring in different plants have characteristic shapes. Laundry starch consists of grains of starch extracted from plants in much the same way as you have extracted potato starch.

THE COMPOSITION OF STARCH

Expt. 110. Heat some dry laundry starch in a dry test-tube, gently at first and then more strongly. What is the colourless liquid which condenses on the cool sides of the test-tube? It looks like water. Test it with cobalt chloride paper or anhydrous copper sulphate. Note the smell. It resembles that of burnt sugar. Put a lighted splint in the mouth of the test-tube. The gas takes fire. What is the appear-

ance of the substance left at the bottom of the test-tube? What substance does it remind you of? Repeat with some more dry starch in another clean test-tube. Fit the latter with a one-holed cork and delivery tube which should lead into lime-water. Now heat the starch. The gas bubbles through the lime-water and turns it milky. Carbon dioxide is present in the gas.

Starch is a compound of the element carbon, and the elements which make up water. It is known as a carbohydrate. This name was given to it, and to other substances like it, when it was believed that it was simply a compound of carbon and water. In one sense it is; but it is not a simple compound. This is shown by the fact that on heating, a gas is given off which smells and another which burns. These cannot be carbon dioxide.

THE ACTION OF WATER ON STARCH

Expt. 111. Put a little starch in cold water in a test-tube, and shake. Does the starch dissolve? Boil the water in which the starch is suspended. At least some of it now dissolves. The appearance of the solution is sometimes called opalescent.

Mix a little starch with cold water so as to make a paste. Add boiling water. A thick gelatinous mass is obtained which, on cooling, sets like a jelly. Take a little of this and add it to cold water. Add iodine solution. The blue colour is obtained.

The granules of starch are insoluble in cold water, but when heated with water the granules swell and burst. The starch inside the granule, called granulose, escapes and dissolves in the hot water, but the starch which forms the wall of the granule is insoluble in hot water. The former is often called 'soluble starch'.

THE ACTION OF DILUTE ACIDS ON STARCH

Expt. 112. Make a weak solution of starch. Cool it, and divide it into four equal portions, *A*, *B*, *C*, *D*. To *A* add one drop of iodine solution, note the blue colour and put the solution aside for reference. To *B* add a few drops of dilute hydrochloric acid and boil for a few minutes. Cool and add one drop of iodine solution. What do you notice about the colour? Compare it with the colour of *A*. There is not so much starch in *B* as in *A*. Some of the starch must have been changed into something else by boiling it with acid. What has it been changed into?

To *C* add a few drops of Fehling's solution, and boil. Put aside for reference. To *D* add a few drops of dilute hydrochloric acid and boil as you did *B*. Now add a few drops of Fehling's solution and boil. Note the yellow-red precipitate. Did you get this precipitate to the same extent (if at all) in *C*?

When starch is boiled with water to which has been added a little dilute hydrochloric acid, the starch is changed to a substance which gives, on boiling with Fehling's solution, an orange precipitate. The substance into which the starch is changed is called glucose. It is a sugar and is soluble in water.

The starch has been very easily changed into sugar. It reacted with water only, the hydrochloric acid acting as a catalyst. There was as much acid left at the end of the reaction as there was to begin with. The reaction was simply between the starch and the water. Any mineral acid will act in this way. We shall learn of other easy ways of changing starch into sugar.

WHAT HAPPENS TO THE STARCH MADE IN THE GREEN PARTS OF THE PLANT?

We have seen that much of the starch made during the day disappears during the night. Where has it gone?

Some of it is used by the plant for growth, and for building other complex foods, but the bulk of it is stored in various parts of the plant. It is characteristic of living things that they do not live from 'hand to mouth', but that they store food in their bodies for a time when they cannot get any food, or for the purpose of reproduction. We shall leave till later the question of why food is needed at all, and shall consider how the plant stores the food it does not immediately need.

When photosynthesis has ceased owing to the absence of light, the sugar in the cell sap is withdrawn from the cell. The starch in the chloroplast is acted upon by a substance called *diastase*. This is an *enzyme*. It has the power of acting catalytically on the starch and converting it to sugar. The latter dissolves in the cell sap and is removed as before. In this way all the starch is converted into sugar and removed from the cell in this soluble form. The insoluble starch could not be moved;

it had to be changed into a soluble substance first. The sugar travels by diffusion, first into the adjacent cells and then into the conducting tissue. It travels along this to the parts of the plant that need the sugar, or to places where it is stored. No doubt such an easily diffusible substance as sugar will pass from place to place by all paths in the plant, but the main channels for the conveyance of the sugar solution seem to be the sheath of the bundles and the elongated cells of the phloem. We shall now look at the structure of the stem again to see the cells used in the transportation of the sugar solution.

THE STRUCTURE OF THE STEM

Examine the stem once again by cutting sections as you did in Experiment 29. This time pay more attention to that part of the bundle that is not wood. Study Figs. 18 and 19. The sunflower stem is a suitable one for this study but it must be remembered that the stems of different plants show differences in detail, and as many stems as possible of different plants should be examined. Do not confine your attention to the microscopic structures. Pull stems to pieces; crush various parts in water and out of water; tease them apart; see if you can find various layers of tissue. Much can be learned in this way with patience. Examine the figures and try to identify the structures in the plant. Prepared slides are very useful and perhaps indispensable, but they should not be used exclusively as they often give an artificial view of the conditions in the plant.

In most stems the wood occurs in that part of the bundle which is nearest to the centre of the stem. Next to the wood, away from the centre, are a number of cells which are noticeable for their regular shape. This part of the bundle is called the *cambium*. The purpose of the cambium is to enable the stem to increase in thickness. This it does by its cells dividing repeatedly. Those cells next to the wood produce more wood cells, those farthest from the wood produce cells which we shall now examine.

The part of the bundle next to the cambium on the outside is called *bast* or *phloem*. The cells are not very regular and are soft. Seen longitudinally most of them seem to be long tubes, separated from one another in the line by cross plates in which there are tiny holes. These plates look like sieves and

the vessels are called *sieve tubes*. It is along these tubes that, to a large extent, the sugar is carried.

Farther out from the soft bast, but still in the bundle, is the hard bast. This is also a conducting tissue, but the walls have been strengthened and thus help to support the plant like the wood vessels.

THE STORAGE OF STARCH

In some plants the sugar brought from the leaves is stored as sugar. For example, the thickened base leaves of the onion plant are very rich in sugar; the root of the carrot contains sugar; the root of the sugar beet is so rich in sugar that the plants are grown for the purpose of extracting it.

Expt. 113. Test each of these plants for sugar by using Fehling's solution. Squeeze a little of the juice into the solution and boil. You will not find much sugar in the sugar beet by this test because the sugar in this plant is cane sugar and not glucose. Test the juice from the sugar beet with iodine solution to show that no starch is present. Then boil a little of the juice with water to which has been added a few drops of dilute hydrochloric acid. This converts the cane sugar to glucose. Now use the Fehling's solution test.

Most plants store the carbohydrate as starch and not as sugar. It is stored in fleshy roots, underground stems, seeds, bulbs, corms, tubers, thick stems, and leaves. The starch grains are formed from the sugar by the action of small bodies called *leucoplasts*. These are like chloroplasts except that they are white instead of green. They are living bodies consisting of very small masses of protoplasm.

A plant stores starch (and other foods) so that it will be available when extra food is required, and also for the purpose of reproduction. The starch stored in the seed gives the plant a supply of food which it can use until it has grown leaves and can manufacture food for itself. There is a large store of food in the seed of the broad bean. The starch stored in the potato is used by the young plant until its leaves are formed above ground. The use which is made of food, however, we shall leave to Ch. XLIV as it is an extensive and important subject. We shall then compare the feeding of plants and animals, and see how all living things use their food.

COMPARISON OF THE PROCESSES OF PHOTOSYNTHESIS AND RESPIRATION IN A PLANT

	<i>Photosynthesis</i>	<i>Respiration</i>
Gaseous exchange with the atmosphere.	Carbon dioxide taken from the air. Oxygen given to the air.	Oxygen taken from the air. Carbon dioxide given to the air.
When the process takes place.	During periods of light.	At all times. Rate increased during rapid growth, e.g. during germination, and decreased during dormant periods.
Where the process takes place.	In all green parts exposed to the light.	In every living cell of the plant.
Chlorophyll.	Necessary.	Not necessary.
How the gases reach and leave the parts.	Mainly through the stomata, and thence by diffusion to the inter-cellular spaces of the green tissue.	Through all permeable parts of the plant's surface and especially through stomata and lenticels, to the inter-cellular spaces, and then by diffusion to all parts. Also through the root hairs.
Nature of the process.	A 'building up' of food reserve (carbohydrates). Corresponds to feeding in animals. 'Dry weight' of the plant is increased.	A 'breaking down' process. The same as respiration in animals. A process of combustion (slow burning). 'Dry weight' of the plant decreased.
Energy.	Light energy of the sun absorbed; transformed and stored as chemical energy. Increase in potential energy (Ch. XLIII).	Energy liberated partly as mechanical energy and partly as heat.

QUESTIONS

1. Who first discovered that oxygen is given off from a plant in the sunlight? How would you demonstrate the fact in the laboratory?
 2. Under what conditions does a plant manufacture starch? How would you test for the presence of (1) sugar (glucose) in the bulb of an onion, (2) starch in a green leaf?
 3. Describe and explain the gaseous exchanges which take place between a plant and the atmosphere (1) at night-time, and (2) during the day.
 4. The proportion of carbon dioxide in the atmosphere remains fairly constant. How is this maintained?
 5. Show how the ordinary green leaf is well adapted to the functions of (a) photosynthesis, (b) respiration, and (c) transpiration.
 6. Account for the presence of starch in the potato tuber. How would you extract some starch from a tuber? Draw a diagram of the appearance of this starch under the microscope.
 7. Give a careful and detailed comparison of the processes of photosynthesis and respiration in a plant.
-

A. Compare and contrast respiration and photosynthesis (carbon assimilation). Why is it incorrect to regard photosynthesis as a special kind of breathing process? [Lond.]

B. It is often stated that animals differ from green plants because they take in oxygen and give out carbon dioxide whereas green plants take in carbon dioxide and give out oxygen. Give a brief account of the processes occurring in animals and plants which result in these gaseous exchanges and explain why the statement as made above is incorrect. [Lond.]

C. How could you prove by experiment that photosynthesis cannot take place if carbon dioxide is not present in the atmosphere? [N.J.B.]

D. Some shoots of water weed were tied to a stone and immersed in water in a beaker and covered by an inverted funnel. A test-tube full of water was inverted over the end of the funnel, the mouth of the test-tube being below the surface of the water in the beaker. A similar apparatus was set up, but, instead of ordinary (or tap) water, contained boiled water and a layer of oil on the surface. Account for the appearance of the test-tubes at the end of two or three days' exposure to sunlight. [Lond.]

VIII

THE COMPOSITION OF WATER

THE ACTION OF SOME METALS ON WATER

1. Calcium

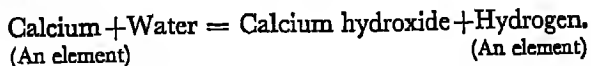
Expt. 114. Examine a piece of calcium. Scrape it with a knife so that you can see the bright white metallic surface. Put a small piece in a large beaker of water. Note what happens. Collect the gas given off by inverting a test-tube full of water over the calcium. Apply a lighted splint to the gas in the test-tube. Note that the light is put out but the gas takes fire. The gas cannot be any of the gases we have studied so far, namely oxygen, nitrogen, and carbon dioxide. Why?

Remove the calcium from the water which now has small particles of a white solid in suspension. Filter the liquid and divide it into two portions in separate test-tubes.

To one tube add reddened litmus solution. It turns blue. There must be some alkaline substance dissolved in the water.

Pass carbon dioxide through the second portion of the liquid. It turns milky. The liquid is lime-water and the alkaline substance must be calcium hydroxide. (The solid in suspension which we removed by filtering the liquid is solid calcium hydroxide that did not dissolve in the water.)

Where has this alkaline substance come from? Where did the gas come from? The gas is called *hydrogen*. It is an element. Calcium is also an element. The hydrogen could not have come from the element calcium, and as it is an element itself, it must have come from the water. Water is a compound of hydrogen.



2. Sodium

Sodium is a soft silvery metal which quickly tarnishes in the air. It is kept either in a sealed vessel, or in a liquid which has no oxygen in its composition, e.g. petroleum or naphtha. Only a small piece should be taken from the liquid at one time and any not needed should be replaced at once. It should not be touched with wet fingers.

Expt. 115. Cut a *small* piece of sodium (about half the size of a small pea) and drop it on the surface of some water in a large dish. Note what happens, but do not get too close as the sodium may 'spit'. The sodium floats as it is less dense than water, becomes globular and rushes about the surface of the water, gradually becoming less until it finally disappears. Test the water with litmus solution. It is alkaline. Was any gas evolved as in the previous experiment?

Expt. 116. Prick some holes in a piece of copper foil and wrap a little sodium in the foil. Let it sink in the water and immediately place an inverted test-tube full of water over the foil to collect any gas given off. You may have to try a few times as the gas is given off

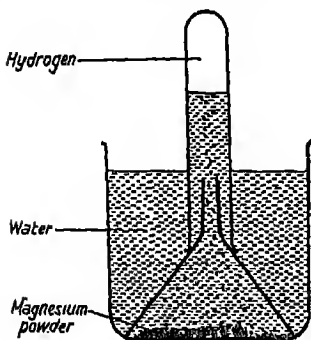


Fig. 83.

very rapidly. Test the gas with a lighted splint. The gas puts the light out but burns itself. The gas is hydrogen. Pass carbon dioxide through the water left. It does not turn milky so no calcium hydroxide is present. This is not surprising as no calcium was used. The alkaline quality of the water must be due to some other alkali.

Sodium + Water =

An alkali + Hydrogen.

3. Potassium

In appearance this metal is very much like sodium and it

is kept and handled in the same way.

Expt. 117. Put a little potassium on water. It behaves like sodium except that the action is more violent. The heat of the reaction causes the hydrogen to burn. The flame is coloured lilac by the potassium. Do not stand too close as the violent reaction may cause pieces to fly out of the water.

Potassium + Water = An alkali + Hydrogen.

4. Magnesium

You have already examined this metal (p. 51).

Expt. 118. Put some magnesium powder in cold water. There is no apparent action, but perhaps it takes longer to show than in the other cases we have examined. Arrange an apparatus as shown in Fig. 83. The powdered magnesium is under the inverted filter funnel, and if any gas is given off it must rise into the test-tube. Leave the

apparatus for a day. Test the gas given off at the end of that time, by a lighted splint. Test the water left with litmus solution. The gas is hydrogen, and the solution is alkaline.

Magnesium + Water = An alkali + Hydrogen.

The action of magnesium on water is like the action of the other metals we have tried, but is much slower. In each case we have obtained the same result in the end, namely hydrogen and an alkali. The speed of the actions differed considerably.

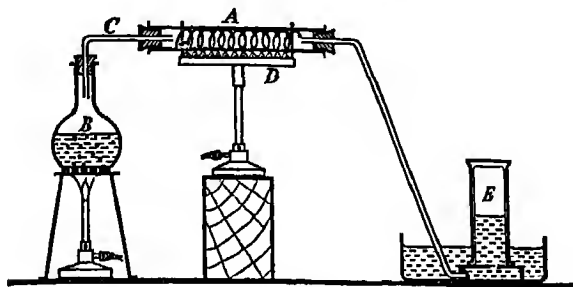
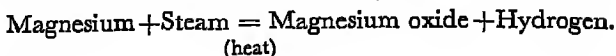


FIG. 84. The preparation of hydrogen.

Potassium had the most violent action, then sodium. The action of calcium was brisk but that of magnesium very slow. All these experiments we performed in the cold. We can increase the rate of the action of magnesium by supplying heat.

Expt. 119. Arrange the apparatus as shown in Fig. 84. *A* is a hard glass combustion tube containing coils of magnesium ribbon. *B* is a flask in which steam is generated. The steam is brought by the delivery tube *C* to *A* and so passed over the magnesium which is heated by the Ramsay burner *D*. This type of burner acts as a support for the hard glass tube and at the same time spreads the flame so that most of the tube is heated. As soon as the steam comes over freely, heat the magnesium strongly until it begins to glow, and then stop heating. At *E* the gas given off is collected over water, the steam being condensed as it passes through the water. When sufficient gas has been evolved, test it with a lighted splint. When the tube is cool enough, examine the substance left in the tube.

The gas evolved is hydrogen; the substance left is a white powder which you have met before, magnesium oxide.



5. Iron

Iron will not act on water in the cold, but when steam is passed over the heated metal, hydrogen is produced, and an oxide of iron left called magnetic oxide of iron so-called because some forms found in nature have magnetic properties (Ch. XXXVI). This method is used commercially on a large scale for the production of hydrogen.

Not all metals will act on water, even when steam is passed over the heated metal. We can tabulate the metals according to the vigour with which they act on water: Potassium, Sodium, Calcium, Magnesium, Iron.

When a metal does act on water, hydrogen is always produced. This comes from the water. When steam is passed over the heated metal the oxide of the metal is produced in addition to hydrogen. The oxygen comes from the water. We shall see that the alkalis formed when metals act on water in the cold are substances related to the oxides of metals.

Our experiments so far have shown that water is a compound of hydrogen. We have not strictly proved that water is also a compound of oxygen, but our experiments indicate that this is probably true. We shall perform an experiment later that will not leave us in any doubt on this question.

THE ACTION OF SOME METALS ON DILUTE ACIDS

1. Magnesium

Expt. 120. Add magnesium ribbon, a little at a time, to dilute hydrochloric acid in a test-tube. Note the gas evolved. Test it with a lighted splint. The gas is hydrogen. Add more magnesium until, on warming, no more will dissolve. Decant the solution left so that it is free from undissolved magnesium. What is this liquid?

We started with dilute acid, i.e. water and hydrochloric acid. Where did the hydrogen come from? It could have come from the water, but we have seen that the action of magnesium on

water in the cold is very slow. It is unlikely that the hydrogen came from the water. Did it come from the acid? If it did, then the acid must be a compound of hydrogen. The magnesium disappeared into the liquid. Is the liquid a solution of magnesium? When salt dissolves in water no gas is given off. When magnesium dissolves in dilute hydrochloric acid, hydrogen is evolved. If we evaporate a solution of salt to dryness we recover the salt. If we evaporate the liquid obtained when magnesium dissolves in dilute hydrochloric acid, shall we get the magnesium back?

Expt. 121. Evaporate the solution obtained in Experiment 120 to dryness. A white powder is obtained which does not look like magnesium.

When magnesium acts on dilute hydrochloric acid, the magnesium removes the hydrogen from the acid and takes its place. The magnesium combines with what is left of the acid after the hydrogen has been removed. The white powder is the substance so formed. It is called magnesium chloride. It is soluble in water. The liquid left in Experiment 120 was a solution of magnesium chloride in water. All (or nearly all) the acid had disappeared.

Magnesium + Hydrochloric acid

= Hydrogen + Magnesium chloride.

Expt. 122. Repeat the experiment using dilute sulphuric acid instead of hydrochloric acid. Instead of evaporating the solution to dryness, stop before all the water has evaporated. Cool the concentrated solution. Colourless crystals of magnesium sulphate are formed. This is the substance Epsom salts.

Magnesium + Dil. Sulphuric acid

= Hydrogen + Magnesium sulphate.

2. Iron

Expt. 123. Repeat Experiments 120 and 122, using iron filings. The gas given off is largely hydrogen, but in this case another gas, having an unpleasant smell, is evolved in addition. It is due to an impurity (carbon) which is nearly always present in iron. Note the colour of the solutions with the two acids. Do not evaporate to dryness, but concentrate the solutions by evaporation, cool, and allow

the substances to crystallize. Note and describe the substances that crystallize out in each case.

Iron + Dil. Hydrochloric acid = Hydrogen + Iron chloride.

Iron + Dil. Sulphuric acid = Hydrogen + Iron sulphate.

3. Zinc

Expt. 124. Repeat the above experiments with granulated zinc. Again hydrogen is evolved with both acids. Try to crystallize out the substances from solution. In the case of hydrochloric acid you will get a dirty white sticky substance which is impure zinc chloride. With sulphuric acid, crystals of zinc sulphate will separate out. Note and describe them.

Zinc + Dil. Hydrochloric acid = Hydrogen + Zinc chloride.

Zinc + Dil. Sulphuric Acid = Hydrogen + Zinc sulphate.

All metals will not act on these two acids, e.g. copper and lead are not dissolved by dilute hydrochloric and sulphuric acids. With nitric acid, metals give off yellowish-brown fumes, which is certainly not hydrogen. But even nitric acid, when very dilute and cold, will give off hydrogen when acted upon by magnesium.

The place of the hydrogen in the acid is taken by the metal. Substances which are formed by the replacement of the hydrogen of an acid by a metal are called *salts*. The salts we have already made in this way are: Magnesium chloride, Iron chloride, Zinc chloride, Magnesium sulphate, Iron sulphate, and Zinc sulphate. Salts of hydrochloric acid are called *chlorides*; those of sulphuric acid are called *sulphates*.

PREPARATION OF HYDROGEN

Hydrogen is often prepared in the laboratory by the action of steam on heated iron (p. 146) but a commoner method is by the action of dilute hydrochloric acid on zinc.

Expt. 125. Fit up an apparatus as in Fig. 85. *A* is a two-necked Woulfe's bottle, which is a convenient piece of apparatus to use when no heating is necessary. Granulated zinc is placed in *A* and covered with water. The thistle-funnel *B* is fitted so that the bottom of the tube is under the water in *A*. *C* is a delivery tube. The gas is collected over water. Pour a little concentrated hydrochloric acid down the

thistle-funnel. When it mixes with the water in the Woulfe's bottle it becomes dilute acid. This acts on the zinc and hydrogen is produced. When one jar is full of the gas replace by another. Collect several jars full. Put a label on the first jar, as this will contain some air as well as hydrogen. This is because the apparatus contained air before the hydrogen was produced.

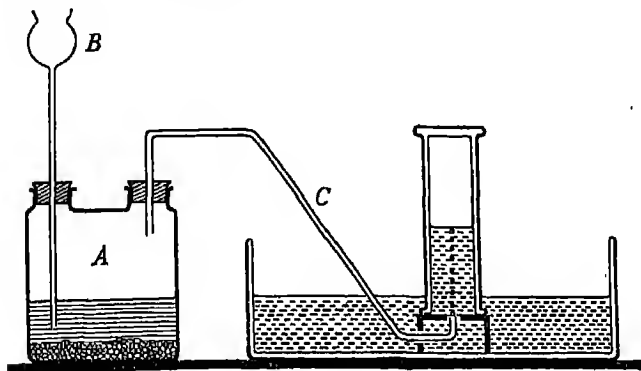


FIG. 85. Preparation of hydrogen.

PROPERTIES OF HYDROGEN

We know some properties already from the preparation and collection of the gas. It is a colourless, odourless gas. If it is soluble in water at all, it is only slightly so, otherwise it could not be collected over water.

Expt. 126. Hold a jar of the gas (not the first one collected) mouth upwards and apply a lighted taper. The gas takes fire immediately, the flame shooting upwards.

Hold a jar of the gas mouth downwards and put a lighted taper right into the jar. The gas burns quietly at the mouth of the jar but the lighted taper is put out. While the gas is still alight withdraw the taper. As it passes through the flame the taper relights. Put the taper in again. The taper is put out.

Hydrogen burns in the air but will not let a lighted taper burn in it. Why did the gas burn quietly when the mouth of the jar was turned downwards, but quickly when the mouth was held upwards? It seems from this that the gas is lighter (less dense) than air. This can be shown as follows:

Expt. 127. Hold two jars, one containing hydrogen and the other air, in the manner shown in Fig. 86. The hydrogen flows upwards as the air flows downwards. Gradually bring the mouths of the jars together and insert lids between them. Test each jar with a lighted splint. The upper jar contains hydrogen, the lower does not, or contains very little. It now contains air.

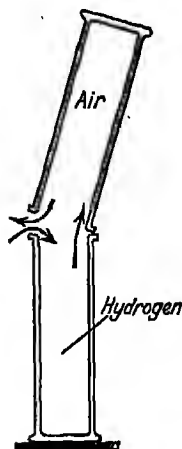


FIG. 86.

Hydrogen is the lightest gas known. Instead of collecting it over water it may be collected by upward delivery. Compare this with the collection of carbon dioxide by downward delivery. The tube must go to the top of the collecting jar otherwise the hydrogen will mix with the air. In any case it will do this a little.

The lightness of hydrogen can be illustrated by passing the gas through caustic soda solution to remove the acid spray that occurs in the Woulfe's bottle, and then blowing soap bubbles with the gas by the aid of a thistle-funnel. The acid is removed as otherwise it would destroy the soap film.

Expt. 128. Wrap a duster round the jar of gas you collected first. Remove the lid and apply a lighted taper. The gas usually lights with an explosion. (It is very unlikely that the explosion will be so violent that the jar will break, but it is always wise to take precautions when bringing a light near to hydrogen. Sometimes the explosion is violent, and bad accidents have been caused by ignorance and carelessness. The duster round the jar prevents the glass from flying if the jar is broken.)

When a light is applied to a mixture of air and hydrogen there is an explosion. The violence of this depends on the proportion of the gases present.

Hydrogen is a colourless, odourless gas, almost insoluble in water, and much lighter than air. It does not allow substances to burn in it, but burns itself with an almost colourless flame. If mixed with air in certain proportions, it explodes when a light is applied.

THE BURNING OF HYDROGEN IN THE AIR

What happens to hydrogen when it burns in the air? We know what happens to some other elements when they burn in the air. They combine with the oxygen of the air to form oxides. When hydrogen burns does it form Hydrogen oxide?

Expt. 129. Fit up an apparatus as in Fig. 87. *A* is a Woulfe's bottle in which hydrogen is prepared as in Experiment 125. *B* is a U-tube

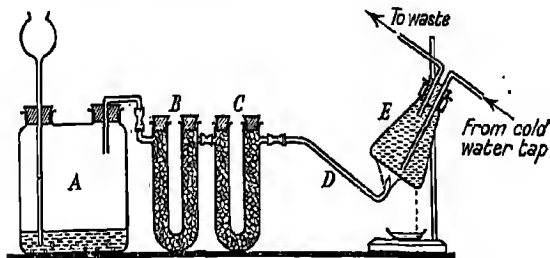


FIG. 87. Burning of hydrogen in air.

containing soda-lime which both dries the gas and removes the acid spray. *C* is another U-tube of soda-lime. This is used as a precaution; if the gas leaves *B* not quite dry, the last trace of moisture is removed in *C*. *D* is a glass tube with a jet at the end. See that all the connexions are tight and that there is no light near the apparatus. Pour concentrated hydrochloric acid down the thistle-funnel, and collect the gas that issues at the jet in a test-tube by upward delivery. Remove the test-tube some distance from the apparatus and apply a light to it. It will burn with an explosion. Repeat this, until on applying a light to the test-tube, the gas burns quietly. You may be sure then, that hydrogen, unmixed with air, is issuing from the jet. Light the hydrogen coming from the jet by applying the quietly burning hydrogen in the test-tube. The gas burns at the jet with a small yellow flame, the colour being given to the flame by the glass. (It is necessary to insist on the light being applied in this way. If a light is applied before the apparatus is free from air there may be a dangerous explosion.)

Watch the flame burning. If hydrogen is like the other elements we have burned in the air, it will combine with the oxygen of the air to form hydrogen oxide. There is no visible product.

Arrange a flask *E* as shown in the figure. The cold water running

through it keeps it cold. Allow the hydrogen flame to touch the bottom of the cold flask. Note what happens.

Drops of a colourless liquid soon appear on the bottom of the flask. Catch the liquid as it falls in a dry evaporating dish. Add anhydrous copper sulphate. It changes colour to blue (or bluish-green). There is water in the liquid.

Where did this water come from? It occurred only in the region near the flame. The hydrogen was dry. It seems that

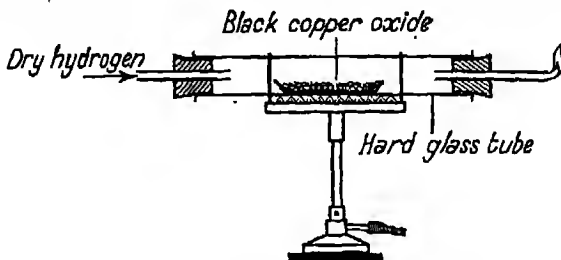


FIG. 88. Action of dry hydrogen on black copper oxide.

when hydrogen is burned in the air, water is formed. We expected to have hydrogen oxide produced. Is water hydrogen oxide?

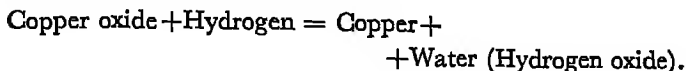
When steam is passed over heated iron, the oxide of iron is formed. This is another indication that water might be hydrogen oxide.

THE ACTION OF DRY HYDROGEN ON BLACK COPPER OXIDE

Expt. 130. Put some black copper oxide in an evaporating dish and heat strongly. Keep the copper oxide stirred all the time with a glass rod. The effect of this heating is to dry the copper oxide. This substance is *hygroscopic*, i.e. it absorbs moisture from the air. Allow the copper oxide to cool in a desiccator. Place some of it in a dry porcelain boat (Fig. 88). Place the boat in a hard glass tube through which is passed hydrogen which has been previously dried. Burn the excess of hydrogen at the jet shown in the figure. Heat the hard glass tube with a Ramsay burner. Watch very carefully what happens in the tube. When moisture appears in the tube between the boat and the jet, stop heating and test the liquid with anhydrous copper sulphate. Fit up the apparatus again and heat very strongly for about ten minutes passing dry hydrogen all the time. Allow the tube to cool,

still in an atmosphere of dry hydrogen. Why? Remove the boat when cool and examine the contents.

The copper oxide has changed into a red powder which is copper. The oxygen lost by the copper oxide has combined with the hydrogen to form water.



REDUCTION AND OXIDATION

The results of Experiment 130 are very important and of great interest. The hydrogen takes oxygen from copper oxide. When a compound loses oxygen during a chemical action, it is said to be *reduced*. The substance which causes the *reduction* is called the *reducing agent*. In this case the copper oxide is reduced to copper by the reducing agent hydrogen.

The hydrogen, during this chemical action, gains oxygen. It is said to be *oxidized*. The substance supplying the oxygen for the *oxidation* is called the *oxidizing agent*. In this case, and in nearly all cases of oxidation and reduction, the oxidizing agent is reduced, and the reducing agent is oxidized.

THE COMPOSITION OF WATER

In Experiment 129 we made water by building it up from its elements hydrogen and oxygen. We made the hydrogen combine with the oxygen of the air. In Experiment 130 we caused hydrogen to take oxygen from copper oxide and so form water. This also was a building-up process. This method is called *synthesis*. The elements are brought together and made to combine.

Can we start with water and split it up into its elements? In other words, can we analyse water? This is the opposite process to that of synthesis. We can do this by electrolysis.

Expt. 131. The electrolysis of water. There are many different ways of performing this experiment. All depend on the fact that if an electric current from a battery or accumulator is passed through water which has been slightly acidulated with sulphuric acid, hydrogen is evolved where one wire enters the water, and oxygen evolved

where the other wire enters. The electric current produces chemical decomposition (Ch. XL), which is the splitting up of a compound into simpler parts. The compound water is split up into its elements hydrogen and oxygen. The experiment is conveniently performed by using a voltmeter, in which the volumes of the gases given off are easily measured.

Fit up the apparatus as shown in Fig. 89 *a*. Pour some water, to

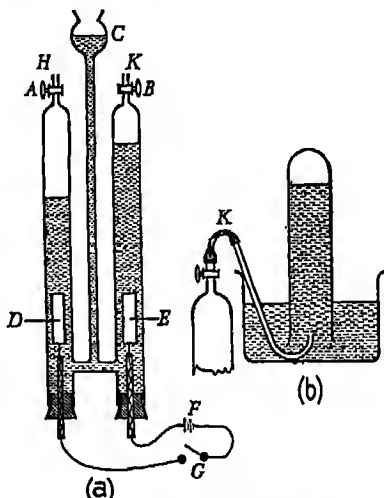


FIG. 89. The electrolysis of water.

which has been added a little dilute sulphuric acid, into the voltmeter at *C*, the taps *A* and *B* being open. When the water reaches the top of the nozzles *H* and *K* close the taps *A* and *B*. The wires from the battery *F* are connected with two platinum electrodes, *D* and *E*. Platinum is used because it is not acted on by any of the substances used in the experiment. The electrode connected with the positive pole of the battery is called the positive electrode or *anode*; that connected to the negative pole is called the negative electrode or *cathode*.

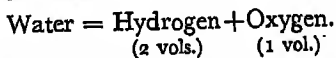
Press the key *G*. The current of electricity passes through the acidulated water and bubbles of gas rise from near each electrode. An electric current will not easily pass through pure water, but it does through water which contains a little sulphuric acid.

As the experiment proceeds, it is soon evident that more gas is coming from the region of one electrode than from the other. When

the action has proceeded for some time, stop the current, and measure the volumes of the gases in the arms of the voltmeter. One is twice the volume of the other.

It is necessary to obtain the gases in separate test-tubes so that they can be examined. The method of doing this is shown in Fig. 89 *b*. The india-rubber tube *K* must be full of water, otherwise you will get air in your test-tube as well as the gas you want to collect. Fix the rubber tube to the nozzle *H* or *K* and collect the gas over water as shown in the figure. To the gas having the smaller volume apply a glowing splint. To that having the larger volume apply a light.

The two gases are oxygen and hydrogen, and there is twice as much hydrogen as oxygen (by volume). We know that it is the water that is decomposed into hydrogen and oxygen, and not the acid, because it can be proved by experiment that just as much acid is left after the experiment as was put into the water at the beginning.



This analysis teaches us more about the composition of water than the synthesis experiments do. We now know not only that water is a compound of hydrogen and oxygen, but that these two gases are combined in the proportion of 2 : 1 by volume. If a mixture of hydrogen and oxygen in this proportion is collected in a strong vessel, and a light applied, the mixture explodes with great violence. Water is produced. The explosion is only rapid combustion. (This experiment should not be performed except by an experienced person.)

THE COMPOSITION OF WATER BY WEIGHT

Very careful experiments have been performed to find what weight of hydrogen is combined with a given weight of oxygen in water. The results show that 1 gm. of hydrogen combines with 8 gm. of oxygen. If we compare these figures with those showing the volume ratio, we see that oxygen must be 16 times as dense as hydrogen.

Expt. 132. To find the composition of water by weight. Fit up the apparatus as in Fig. 90. Hydrogen prepared from zinc and dilute sulphuric acid in *A* is passed into potassium permanganate solution in *B* to purify the gas. It is then dried by the calcium chloride

in *C*, and passed over copper oxide in a porcelain boat in *D*. As it is hygroscopic, the copper oxide should previously be heated to redness in the boat, cooled in a desiccator, and weighed with the boat. The gas then passes through *E* containing calcium chloride to collect the water formed. Tube *F* also contains calcium chloride. The tubes *E* and *F* should be weighed separately, care being taken that the ends of the tubes are closed by clips during the weighing operations. Why? The tube *D* is heated for about 15 minutes and is cooled in a stream of hydrogen to prevent the copper being partially reoxidized by oxygen from the air.

The boat and residue, and the tubes *E* and *F*, are then reweighed

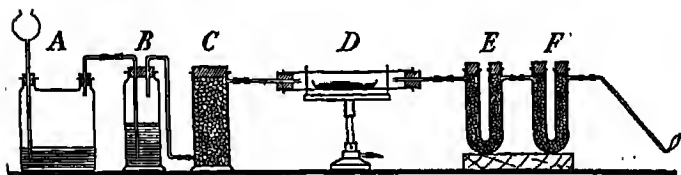


FIG. 90. The composition of water.

separately. If *F* has increased in weight it means that some water has passed over from *E*, and therefore possibly some may have escaped into the air. In this case the experiment will have to be repeated. If *F* remains the same weight, then all the water formed will have been absorbed by *E*.

Table of Results

Gm.

Weight of boat + copper oxide	
Weight of boat + copper (after passing hydrogen)	
Therefore weight of oxygen (i.e. loss in weight of boat and contents)	x
Weight of U-tube <i>E</i>	
Weight of U-tube <i>E</i> after passing hydrogen	
Weight of water formed (i.e. increase in weight of <i>E</i>)	y
Weight of hydrogen used	$y - x$
x gm. of oxygen combine with $y - x$ gm. of hydrogen	
$\frac{x}{y - x}$ gm. of oxygen combine with 1 gm. of hydrogen	

The approximate result will be 8 gm. of oxygen to 1 gm. of hydrogen. This experiment has been performed with elaborate apparatus to eliminate all possible error, and the result obtained is 7.9395 : 1. For ordinary purposes the ratio 8 : 1 is

sufficiently accurate. So we can say 9 gm. of water contain 8 gm. of oxygen and 1 gm. of hydrogen.

OTHER USES OF HYDROGEN

Hydrogen is used to harden vegetable and animal oils in the presence of finely divided nickel, and in the manufacture of margarine and soaps. If a flame of hydrogen is fed with oxygen, a very high temperature is reached. This is used in the Oxy-hydrogen blow-pipe which is used for welding iron and other metals, e.g. aluminium, copper; for melting platinum, and for fusing quartz in the manufacture of quartz vessels.

Coal-gas contains about half its volume of hydrogen and is, of course, used for lighting and heating. Water-gas, a mixture chiefly of hydrogen and carbon monoxide, is also used as a fuel. These gases will later be described in detail (Ch. X).

Hydrogen is also used in the manufacture of synthetic ammonia, by combining it with nitrogen, using pressure.

Another very important and modern use of hydrogen to be described later (Ch. X) is the manufacture of petrol from coal.

QUESTIONS

1. What metals will react with cold water to produce a gas? What is the gas, and what is left in solution in each case? What does this prove about the composition of water?
2. What happens to hydrogen when it is burned in the air? What does this prove about the composition of water? How may water be split up into its constituent elements? Does this give us any further information about the composition of water?
3. Explain the terms oxidation and reduction by giving examples in which water is concerned.
4. State the laboratory and industrial uses of hydrogen. Give details of one industrial process in which hydrogen is used.
5. What is the composition of water by (a) volume, (b) weight? State briefly, without experimental detail, how you could demonstrate these facts. What do these facts tell us about the relative densities of hydrogen and oxygen?

IX

THE COMPOSITION OF MATTER

IS MATTER CONTINUOUS OR DISCONTINUOUS?

It will help us to understand chemical reactions better if we consider the constitution of matter. Apart from the usefulness of this study, it is of great interest in itself and has attracted the attention of thinkers throughout the ages. The Ancient Greeks made guesses at it and argued about it. The question as it appeared to them was: Is matter continuous or discontinuous? In other words: Is matter made up of tiny particles as a house is made up of bricks, or is it 'one piece'?

Suppose you divide a drop of water into two parts and then divide each drop into two again, and so on. It is clear that soon it will be impossible to divide it any farther because the piece will become too small to handle. But suppose you go on dividing it in imagination. How far could you go? Would you, in the end, come to a piece that could not be divided, or would you be able to go on for ever?

Some Greek philosophers held one view, and some the other. It was really impossible to decide between the two views, because there was no evidence either way. It was not until 1803 that JOHN DALTON, an English chemist, put forward evidence which favoured one view more than another. In 1811, AVOGADRO, an Italian physicist, added to Dalton's theory. At the present time all students of chemistry accept Dalton's ideas as supplemented by Avogadro's work.

MOLECULES

Consider the element sulphur. It is supposed to be built up of tiny particles of sulphur called *molecules* of sulphur. The molecules are the 'bricks' which make up the 'building', a piece of sulphur. A molecule of sulphur is the smallest piece of sulphur that can exist as sulphur. A piece of sulphur is just a collection of many millions of molecules of sulphur. The

molecules are not supposed to be touching each other, but to be at a distance from each other which is great compared with the size of the molecule. The latter are so small that even a speck of sulphur contains many millions of molecules. They cannot be seen even with the most powerful microscope. The distance between molecules, although much greater than the size of the molecule, is also very small. All the molecules of sulphur are supposed to be exactly alike. It is the same with other elements. They are composed of their own type of molecule.

Now consider the compound calcium carbonate. A piece of calcium carbonate consists of a great number of molecules of calcium carbonate. If a molecule of calcium carbonate is divided, the result will not be calcium carbonate, because a molecule of that substance is the smallest portion which can exist. When calcium carbonate is heated, calcium oxide and carbon dioxide are produced. Each molecule of calcium carbonate splits up into two molecules, one of carbon dioxide and one of calcium oxide. This does not mean that a molecule of calcium carbonate consists of a molecule of calcium oxide combined with a molecule of carbon dioxide. The molecule is not so simply arranged as that.

ATOMS

A molecule of calcium carbonate contains carbon, calcium, and oxygen. These are elements. The least portion of an element that can exist independently is a molecule, but it is not necessary to suppose that the least portion of oxygen that can be in a molecule of calcium carbonate is a molecule of oxygen, because the oxygen in calcium carbonate is not existing independently. The smallest portion of an element that can exist in the molecule of a compound is called an *atom*. This is defined as the smallest portion of an element that can take part in a chemical change. When hydrogen is passed over heated copper oxide, the hydrogen consists of millions of molecules of that gas, and the copper oxide consists of millions of molecules of that solid; but it is the atoms of hydrogen that combine with atoms of oxygen to form molecules of water.

In all ordinary chemical operations atoms are considered to be *uncreatable, indestructible, and indivisible*. All the atoms of the same element are alike in chemical properties, and the atoms of different elements differ in their chemical properties. Compounds are formed by the union in simple numbers of atoms of different elements.

Let $\textcircled{\text{H}}$, $\textcircled{\text{O}}$ and $\textcircled{\text{Cu}}$ represent atoms of hydrogen, oxygen and copper respectively.

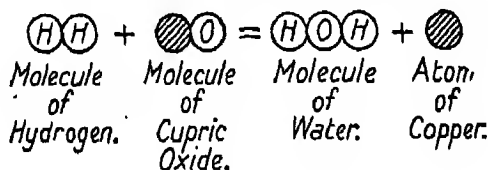
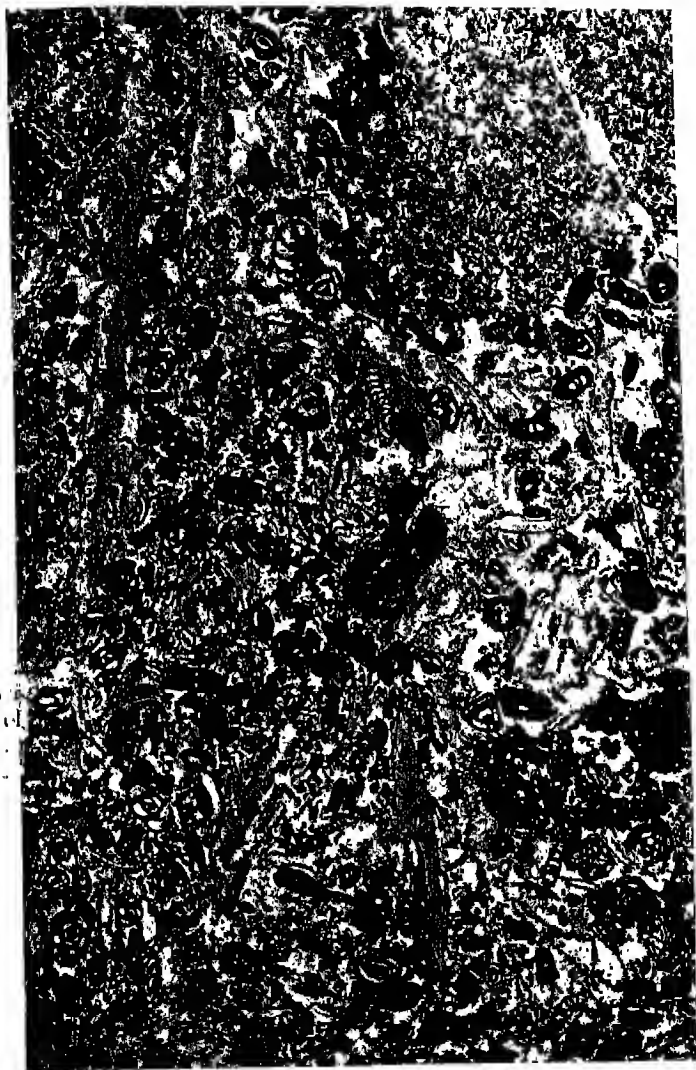


FIG. 91.

MOLECULES OF COMPOUNDS AND OF ELEMENTS

A molecule of a compound may consist of one atom of one element combined with one atom of another element; or it may consist of one atom of one element combined with two atoms of another element; or there may be present in one molecule of a compound the atoms of several different elements. The molecules of some compounds are comparatively large, consisting of many atoms of several different elements.

A molecule of an element may consist of one, two, three, or even more atoms of the same element. The molecules of most gases which are elements, consist of two atoms to the molecule (*DI-ATOMIC*). In the case of some solid elements the constitution of the molecule is known, e.g. sulphur has eight atoms to the molecule and phosphorus four in the solid state. Many metals in the gaseous state are *MON-ATOMIC*, i.e. they have one atom to the molecule. For most chemical purposes it is convenient to *assume* that solid elements are mon-atomic.



IV. Microphotograph of *Foraminifera* in limestone

THE LAW OF CONSERVATION OF MATTER

In all chemical experiments we assume that no new matter is ever created and that none is ever destroyed. When hydrogen reacts with copper oxide, the sum of the weights of hydrogen and copper oxide used is equal to the sum of the weights of the water and copper obtained. Men have tried to find a gain or a loss in weight during a chemical reaction, and very delicate balances have been used to detect any possible change; but no one has ever discovered any change in weight that could not be accounted for by the errors of the instruments used. Every chemical operation performed where weighing is done assumes that no matter is destroyed and that none is created. This fact is known as the **LAW OF CONSERVATION OF MATTER**. It is usually stated: *matter cannot be created or destroyed*; then it follows that atoms cannot be created or destroyed. You have probably heard of atoms being split and atomic energy released but this is a special process which we deal with later (Ch. XX). Atoms are never split during chemical reactions.

A scientific law is merely a statement of what we believe to be true. It is a general statement, and is often called a generalization. It has usually been established by observation and experiment conducted by many people at various times and in many places and under varying conditions. We have increasing confidence in a law every time experiment or observation in a particular case confirms it. Nevertheless it is unscientific to have complete confidence in any scientific law, because some day further knowledge may cause us to modify it.

THE LAW OF CONSTANT COMPOSITION

The same compound always contains the same elements combined in the same proportion by weight. For example: When water is analysed it is found that 1 gm. of hydrogen combines with 8 gm. of oxygen. This is true no matter what the source of the water so long as it is pure water. Pure calcium carbonate, no matter where or how obtained, always contains in every 100 gm., 40 gm. of calcium, 12 gm. of carbon, and 48

gm. of oxygen. This is because the molecule of calcium carbonate always contains one atom of calcium, one atom of carbon, and three atoms of oxygen; and that the relative weights of these atoms to each other are 40 : 12 : 16. If we take one each of the first two and three of the last, the relation becomes 40 : 12 : 48.

Now we can better understand the difference between compounds and mixtures. All the molecules of a compound are alike, those of a mixture are not.

EQUIVALENTS (EQUIVALENT WEIGHTS)

We have seen in the previous paragraph that the elements of which a pure chemical compound is composed are always present in constant proportions by weight. In order to compare these combining weights it is much simpler if we choose one element as our standard and then determine the weights of the other elements which combine with one part by weight of our standard element. Hydrogen is chosen as the standard because it has the smallest combining weight.

On p. 156 (Expt. 132) we found that 1 gm. of hydrogen combines with 8 gm. of oxygen. We can say that the *equivalent* of oxygen is 8. Note that we do not say 8 gm. The equivalent of oxygen is a *number* which tells us how many parts by weight of oxygen combine with one part by weight of hydrogen. Eight gm. is said to be the gram-equivalent of oxygen because this weight combines with 1 gm. of our standard element, hydrogen. Gram-equivalents are often used in ordinary chemical work.

We have seen (p. 146) that some metals, e.g. magnesium, iron, and zinc displace hydrogen from dilute hydrochloric or sulphuric acid. It is possible, as we shall see, to find the weight of hydrogen displaced by a given weight of metal when it acts on an acid. Twelve gm. of magnesium displace 1 gm. of hydrogen from hydrochloric acid and also from sulphuric acid. Now we shall see (Expt. 134) that when magnesium combines with oxygen, 12 gm. of magnesium combine with 8 gm. of oxygen. But we have seen that 1 gm. of hydrogen combines with 8 gm. of oxygen. Similarly 33 gm. of zinc displace 1 gm. of hydrogen

from an acid and 33 gm. of zinc combine with 8 gm. of oxygen. In the examples we have chosen, the same weight of metal which combines with 8 gm. of oxygen also displaces 1 gm. of hydrogen from acids. Metals do not usually combine with hydrogen to form stable compounds but the non-metal carbon combines with both hydrogen and oxygen. In methane 3 gm.

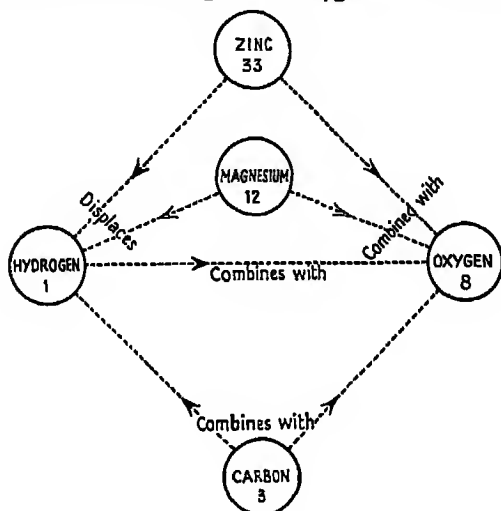


FIG. 92.

of carbon combine with 1 gm. of hydrogen, and in carbon dioxide 3 gm. of carbon combine with 8 gm. of oxygen. That is, the same weight of carbon (3 gm.) combines with 1 gm. of hydrogen and 8 gm. of oxygen.

As 3 gm. of carbon combine with 1 gm. of hydrogen we say that the equivalent of carbon is 3. But the equivalent of oxygen is 8. That is, the equivalent weight of carbon combines with the equivalent weight of oxygen. This enables us to extend our idea of equivalents and say that the equivalent of an element is the number of parts by weight of that element which combines with 1 part by weight of hydrogen or 8 parts by weight of oxygen. That being so the equivalents of magnesium and zinc

are 12 and 33 respectively. But these are the weights of the metals which displace 1 gm. of hydrogen from acids. So we may make a further extension of the idea of equivalents. *The equivalent (or equivalent weight) of an element is defined as the number of parts by weight of that element which will combine with or displace one part by weight of hydrogen or 8 parts by weight of oxygen.* Fig. 92 illustrates this for the elements mentioned above.

DETERMINATION OF EQUIVALENTS

1. By displacement of hydrogen

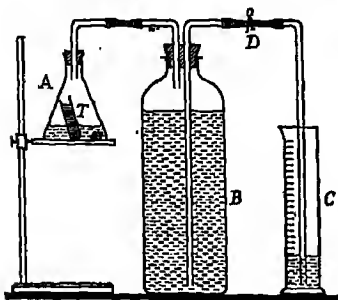


Fig. 93.

Expt. 133. To find the weight of zinc which will displace 1 gm. of hydrogen from hydrochloric acid. Fit up the apparatus as illustrated in Fig. 93. *A* is a small flask containing water and a tube (*T*) of concentrated hydrochloric acid. *B* is a 'Winchester quart' containing water and connected by a siphon to a graduated cylinder *C*. The siphon tube is, of course, full of water.

Weigh accurately about 1 gm. of zinc and place it in flask *A* as indicated. First test the apparatus by opening clip *D*. A little water will run out of the delivery tube, but the flow will soon cease if the apparatus is air-tight. The apparatus must be air-tight before proceeding. Raise *C* so that the levels of the water in *B* and *C* are the same. Close clip *D* and replace *C*. Note the level of water in *C*. Open clip *D*, tilt flask *A* so that the acid comes in contact with the zinc and water. Hydrogen is given off, and passing into the Winchester quart (of course with some air from the flask) drives out an equal volume of water into the cylinder *C*.

Allow to cool, since flask *A* has been warmed as a result of the chemical reaction. It is essential that the delivery tube should be dipping under the water in *C* all the time. Raise *C* as before until the levels of the water in *B* and *C* are the same. Close *D* and read the level of the water in *C*. The liquids are levelled because it is essential that the volume should be read at atmospheric pressure. The temperature of the apparatus (the water in *B*) is taken, also the atmospheric pressure as registered on a barometer.

The volume of hydrogen liberated at atmospheric pressure and temperature has been determined. This volume is next reduced to

N.T.P. (Ch. XXIV). The *weight* of hydrogen is then determined by making use of the fact that 1 litre of hydrogen at N.T.P. weighs 0.09 gm. This weight of hydrogen has been evolved from the acid by the action of the weight of zinc taken. From this the weight of zinc which could displace 1 gm. of hydrogen can then be determined.

2. By oxidizing a metal

Expt. 134. To find the weight of magnesium which will combine with 8 gm. of oxygen. Follow the details of Experiment 47 on p. 54.

<i>Weighings and Calculation</i>	<i>Gm.</i>
Weight of crucible+lid	
Weight of crucible+lid+magnesium	
Weight of magnesium taken	x
Weight of crucible+lid+magnesium oxide (i)	
Constant (ii)	
Weight of oxygen combined with the magnesium	y
y gm. of oxygen combine with x gm. of magnesium	
1 gm. of oxygen combines with x/y gm. of magnesium	
8 gm. of oxygen combine with $8x/y$ gm. of magnesium	
Equivalent of magnesium = $8x/y$.	

3. By the reduction of a metallic oxide

Expt. 135. To find the weight of copper combined with 8 gm. of oxygen in cupric oxide. Follow the details of Experiment 130 on p. 152, but weigh the boat, copper oxide taken, and copper obtained.

<i>Weighings and Calculation</i>	<i>Gm.</i>
Weight of boat	
Weight of boat+copper oxide	
Weight of copper oxide taken	x
Weight of boat+copper obtained (i)	
Constant (ii)	
Weight of copper obtained	y
Weight of oxygen lost	$x-y$
$x-y$ gm. of oxygen combine with y gm. of copper	
8 gm. of oxygen combine with $8y/(x-y)$ gm. of copper	
Equivalent of copper = $8y/(x-y)$	

ATOMIC WEIGHTS

We have seen that atoms of different elements differ in weight. The actual weights are very small and formerly they were unknown. The *relative weights* of the atoms, however, have been found with great accuracy. It is found more

convenient to deal with these relative weights of the atoms rather than with their actual weights, although the latter are now known. The hydrogen atom is the lightest, so the atomic weight of hydrogen is called 1. Now the atom of oxygen has been found to be 16 times as heavy as the hydrogen atom so we say that the atomic weight of oxygen is 16.

The number of times one atom of the element is heavier than one atom of hydrogen.

The ATOMIC WEIGHT OF AN ELEMENT is defined.

The approximate atomic weights of the commoner elements are given on p. 168. These approximate atomic weights are the ones usually used in elementary chemistry. More accurate ones are used only when necessary.

When we compare the atomic weights of the elements with their equivalent weights we find that the atomic weight is either the same as the equivalent weight or is a simple multiple of it.

For example: the atomic weight of sodium is 23, the same as its equivalent weight; the atomic weight of oxygen is 16, which is twice the equivalent weight; the atomic weight of aluminium is 27, which is three times its equivalent weight, and the atomic weight of carbon is 12, which is four times the equivalent weight.

The number by which the equivalent weight is multiplied to give the atomic weight is called the *valency* of the element.

Atomic weight = Equivalent weight \times Valency.

Thus the valency of sodium is 1, oxygen 2, aluminium 3, and carbon 4.

The idea of valency was not arrived at originally in this way. As you advance in your study of chemistry you will attach a much wider meaning to the term valency than is used here.

SYMBOLS AND FORMULAE

It is often found convenient in Chemistry to represent atoms by *symbols*. Thus one atom of hydrogen is represented by H, one atom of carbon by C, and one atom of nitrogen by N.

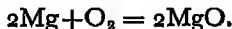
Usually the initial letter of the name of the element is used, but sometimes this is impossible. Calcium cannot be represented by C because that is the symbol for one atom of carbon. The next letter is added, but not in capitals. One atom of calcium is represented by Ca. Sometimes the first two letters of the Latin name of the element are used. Thus one atom of copper is represented by Cu. A list of all the elements mentioned in this course is given with their symbols and atomic weights on p. 168. The connexion between the symbol and the element is also indicated.

If it is desired to write two atoms of an element a figure 2 is written before the symbol, e.g. 2H means two atoms of hydrogen, 3Cu means three atoms of copper.

Using these symbols it is possible to write *formulae* for the molecules. Hydrogen has two atoms to the molecule, which is represented by H_2 and not 2H . The formula for the molecule of a compound is made by writing side by side the symbols of the elements in the compound, indicating with a number after them how many atoms there are of each kind. Thus CO_2 represents a molecule of carbon dioxide, and shows that in a molecule of that compound there are two atoms of oxygen combined with one atom of carbon. One molecule of water is represented by H_2O , and one of calcium carbonate by CaCO_3 . When it is desired to show that two molecules are intended, that number is written before the formula, thus, 2CaCO_3 .

EQUATIONS

Using these formulae it is possible, and often convenient, to represent chemical actions by means of equations. The following is an equation for a reaction we have already studied:



Study Fig. 94 which illustrates the meaning of this equation: Note that molecules of gases and atoms of solid elements are represented

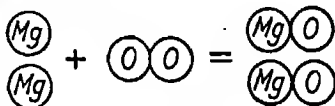


FIG. 94.

in equations. This is why we write O_2 and not O. We write

2Mg and not Mg_2 because 2Mg means 2 atoms of magnesium. Mg_2 would mean one molecule of magnesium assuming the

<i>The commoner elements</i>	<i>Symbol</i>	<i>Atomic weight (approx.)</i>
Aluminium	Al	27
Arsenic	As	75
Barium	Ba	137
Bromine	Br	80
Calcium	Ca	40
Carbon	C	12
Chlorine	Cl	35.5
Chromium	Cr	52
Cobalt	Co	59
Copper (Cuprum) . .	Cu	63.5
Fluorine	F	19
Helium	He	4
Hydrogen	H	1
Iodine	I	127
Iron (Ferrum) . . .	Fe	56
Lead (Plumbum) . .	Pb	207
Magnesium	Mg	24
Manganese	Mn	55
Mercury (Hydrargyrum)	Hg	201
Nickel	Ni	59
Nitrogen	N	14
Oxygen	O	16
Phosphorus	P	31
Potassium (Kalium) .	K	39
Silicon	Si	28
Silver (Argentum) . .	Ag	108
Sodium (Natrium) . .	Na	23
Sulphur	S	32
Tin (Stannum) . . .	Sn	119
Zinc	Zn	65

molecule to be diatomic. The structure of the molecules of the solid elements is often very complex and we assume that their atoms enter into the reaction separately.

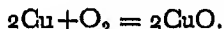
The number and kind of atoms on the right-hand side is the

same as on the left-hand side. This must be so if the Law of Conservation of Matter is true.

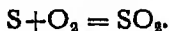
The equation is interpreted: Two atoms of magnesium react with one molecule of oxygen to form two molecules of magnesium oxide.

There is much information that the equation does not give. It does not say whether heat is required, or whether the substances employed are solids, liquids, or gases. It does not tell whether the action is slow or violent. Chemistry can never become an exercise in forming equations, nevertheless the equations are very useful.

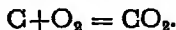
It is intended that the following equations shall serve two purposes: to familiarize you with the use of equations, and at the same time revise reactions which we have already studied. All reactions represented by the equations have been dealt with previously. You should refer to them as you study the equations.



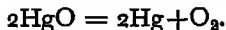
Two atoms of copper combine with one molecule of oxygen to form two molecules of cupric oxide.



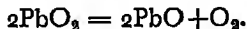
One atom of sulphur combines with one molecule of oxygen to form one molecule of sulphur dioxide.



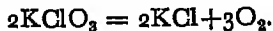
One atom of carbon combines with one molecule of oxygen to form one molecule of carbon dioxide.



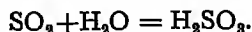
Two molecules of mercuric oxide decompose into two atoms of mercury and one molecule of oxygen.



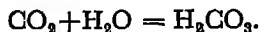
Two molecules of lead peroxide decompose into two molecules of lead monoxide and one molecule of oxygen.



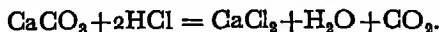
Two molecules of potassium chlorate decompose into two molecules of potassium chloride and three molecules of oxygen.



One molecule of sulphur dioxide reacts with one molecule of water to form one molecule of sulphurous acid.



One molecule of carbon dioxide reacts with one molecule of water to form one molecule of carbonic acid.



One molecule of calcium carbonate reacts with two molecules of hydrochloric acid to form one molecule of calcium chloride, one molecule of water, and one molecule of carbon dioxide.



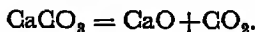
One molecule of calcium carbonate reacts with one molecule of sulphuric acid to form one molecule of calcium sulphate, one molecule of water, and one molecule of carbon dioxide.



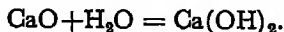
Two molecules of sodium bicarbonate decompose into one molecule of sodium carbonate, one molecule of water, and one molecule of carbon dioxide.

The following equations are given without interpretation. Refer to the summary (p. 83) and try to interpret the equations:

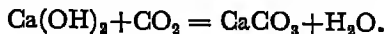
The action of heat on chalk (calcium carbonate).



The action of water on calcium oxide (quick-lime).



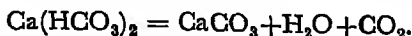
The action of carbon dioxide on lime water (a solution of calcium hydroxide).



The action of carbon dioxide on a suspension of calcium carbonate in water.



The action of heat on a solution of calcium bicarbonate in water.

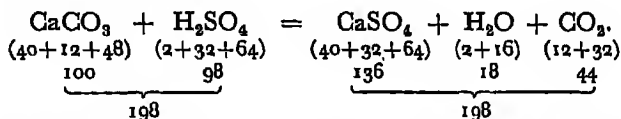


REACTING WEIGHTS

We have interpreted the above equations as statements of reacting atoms and molecules. We can also interpret them as statements of reacting weights.

The *molecular weight* of a substance (element or compound) is the weight of one molecule of the substance compared with the weight of one atom of hydrogen. Thus it is the sum of the atomic weights of all the atoms in the molecule; e.g. the molecular weight of hydrogen, H_2 is 2, oxygen, O_2 is 32, calcium carbonate, CaCO_3 is $(40 + 12 + 3 \times 16) = 100$. This means that 1 molecule of calcium carbonate is the weight of 100 atoms of hydrogen.

Consider the equation



We have already interpreted this equation as a statement of reacting molecules, i.e. 1 molecule of calcium carbonate reacts with 1 molecule of sulphuric acid to give 1 molecule of calcium sulphate, 1 molecule of water, and 1 molecule of carbon dioxide. Below the formulae are written the molecular weights of the molecules concerned in the reaction. As these are, by definition, referred to the same standard (the weight of 1 atom of hydrogen) it is clear that these numbers represent the relative weights of the substances in the reaction. The equation may now be interpreted as follows: 100 parts by weight of calcium carbonate react with 98 parts by weight of sulphuric acid to give 136 parts by weight of calcium sulphate,

18 parts by weight of water, and 44 parts by weight of carbon dioxide.

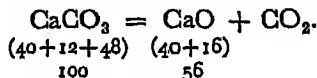
The sum of the reacting weights on one side of an equation is, of course, equal to the sum of the reacting weights on the other side, otherwise it would not be, in accordance with the Law of Conservation of Matter.

Instead of 'parts by weight' we may write 'grams', or 'lb.', or any other unit of weight, and in calculations it is usual to do so.

Examples

1. What weight of quicklime can be obtained by heating 1 ton of limestone?

We first write the equation for the reaction.

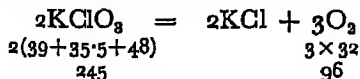


As we are not concerned with the carbon dioxide in this problem it is unnecessary to calculate its molecular weight. All that is necessary is that the equation should be correct.

100 tons of limestone yield 56 tons of quicklime.

Therefore 1 ton ,, ,, yields 0.56 ,, ,, ,,

2. What weight of potassium chlorate will yield 5 gm. of oxygen when the potassium chlorate is heated?



This time we are not concerned with the potassium chloride so we can neglect it. Note also that we have 2 molecules of potassium chlorate and 3 molecules of oxygen so the molecular weights must be multiplied by 2 and 3 respectively.

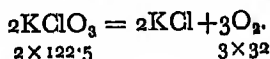
96 gm. of oxygen are obtained from 245 gm. of potassium chlorate.

5 gm. of oxygen are obtained from $\frac{245 \times 5}{96} = 12.76$ gm. of potassium chlorate.

REACTING WEIGHTS AND VOLUMES

In the last problem we dealt with the weight of a gas. It is much more convenient to deal with the volumes of gases rather than with their weights because it is difficult to weigh gases but easy to find their volumes.

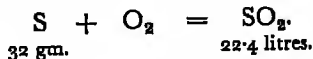
The molecular weight of a substance, with the word grams written after it, is called the *gram molecular weight* (or *gram molecule*) of the substance. The molecular weight of oxygen is 32 and its gram molecular weight is 32 gm. It is known that the gram molecular weight of any gas occupies 22.4 litres when measured at N.T.P. (Ch. XXIV). It is not necessary to give the proof in a book on General Science, but it is a useful fact and should be remembered. It means, for example, that 2 gm. of hydrogen, 32 gm. of oxygen, or 71 gm. of chlorine all occupy 22.4 litres at N.T.P. Let us consider in this light the equation



Now 32 gm. (i.e. the gram molecular weight) of oxygen occupies 22.4 litres at N.T.P. So for every 32 gm. we have 22.4 litres. We can, therefore, interpret the equation as follows:

245 gm. of potassium chlorate when heated yields 67.2 (i.e. 3×22.4) litres of oxygen at N.T.P.

Example. What volume of sulphur dioxide measured at N.T.P. is obtained when 4 gm. of sulphur are burnt completely in air or oxygen?



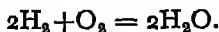
Note that (i) we are not concerned in this calculation with either the weight or volume of oxygen, (ii) we need not find the gram molecular weight of sulphur dioxide as we know this is represented by the formula of the molecule, and we can write 22.4 litres for every molecule.

32 gm. of sulphur yield 22.4 litres of sulphur dioxide at N.T.P.

4 " " " " 2.8 " " " " " "

REACTING VOLUMES

Sometimes we have a problem to solve which deals only with the volumes of gases and no weights are given. Consider the equation



Two molecules of hydrogen combine with 1 molecule of oxygen to form 1 molecule of water. Then when the gases are measured at N.T.P. 2×22.4 litres of hydrogen combine with 22.4 litres of oxygen to form water. It follows, then, that 2 volumes of hydrogen combine with 1 volume of oxygen to form water, and this is true whether the volumes are measured at N.T.P. or not, so long as they are measured at the same temperature and pressure.

We cannot deal with water in the same way because water is a liquid below $100^\circ \text{C}.$, but if we measured the volumes of the gases at some temperature above $100^\circ \text{C}.$ we could interpret the equation thus: 2 volumes of hydrogen combine with 1 volume of oxygen to form 2 volumes of steam. Thus 10 c.c. of hydrogen produce 10 c.c. of steam if they are both measured at the same pressure and temperature above $100^\circ \text{C}.$

Further examples involving the interpretation of equations will be given when we have studied more chemical reactions.

QUESTIONS

1. Define (a) atom, (b) molecule. Interpret the following equation as a statement of reacting molecules:



What important facts about this reaction does this equation *not* tell you?

2. State the Law of Constant Composition and explain it by means of an example.

3. What are the differences between a mixture and a compound? Illustrate by giving examples.

4. Interpret the equations given on p. 170.

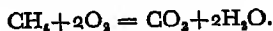
5. Explain carefully, giving examples, what is meant by the term equivalent weight. What is its relation to the atomic weight of an element?

6. Some mercuric oxide was heated strongly until it was all decomposed into mercury and oxygen. The following weighings were obtained: Weight of mercuric oxide heated = 2.18 gm.; Weight of mercury left = 2.02 gm. Calculate the equivalent weight of mercury.

7. What volume of carbon dioxide (measured at N.T.P.) is evolved when 5 gm. of calcium carbonate are treated with sufficient dilute acid?

8. What weight of magnesium is required to make 10 gm. of magnesium sulphate? What weight of sulphuric acid is used in the process?

9. When the gas methane (CH_4) is completely burnt in oxygen the reaction may be represented by the equation:



What volume of oxygen is required for the complete combustion of 500 c.c. of methane and what volume of carbon dioxide is produced, assuming that the gases are measured at the same temperature and pressure.

EXAMINATION QUESTIONS

1. A four-foot length of wide glass tubing is sealed at one end and a small muslin bag of iron filings is pushed into it so that the bag is wedged tightly at the sealed end. The tube is then half filled with water, inverted in a dish of water and left out-of-doors for some time.

Discuss the physical and chemical factors which may affect the level of the water in the tube. Make a drawing of the arrangement showing the approximate level which the water will ultimately reach.

[N.J.B.]

2. How would you obtain hydrogen from (a) cold water, (b) steam, (c) dilute acid? Describe experiments (one in each case) to show (a) that hydrogen is lighter than air, (b) that water is formed when hydrogen burns in the air.

[Lond.]

3. Give diagrams of the external features and internal mechanism of a stirrup pump. Explain how atmospheric pressure is used to furnish a jet of water in this pump. How is the jet maintained during the downward stroke of the plunger? Name two places in the pump where leakage is likely to occur.

[Lond.]

4. What is meant by respiration? What are the characteristic differences between the respiratory processes of (a) a higher animal and a green plant, (b) a man and a tadpole.

[N.J.B.]

5. Leaves from two different potted plants were taken, decolorized by removing the chlorophyll and treated with iodine solution. Leaf *A* showed a dark stain, leaf *B* did not.

(i) Describe one method by which the decolorization could have been carried out.

(ii) What substance was shown by this test to be present in leaf *A*?

(iii) What suggestion can you make as to the conditions in which the two plants had respectively been kept for a period just before the leaves had been picked? [N.J.B.]

6. Carefully explain how you would proceed to discover what gas, or gases, are given off by germinating green pea seeds. [Lond.]

7. Draw a diagram of the apparatus you would set up to demonstrate that (a) a potato, (b) a small animal such as a frog or mouse, gives off carbon dioxide during respiration. Would any special precautions have to be taken if, instead of the potato or animal, you substituted a small green potted plant? [Lond.]

8. How would you show that carbon dioxide (a) is heavier than air, (b) can be used to put out a petrol fire, (c) contains carbon? Describe an experiment to show that carbon dioxide is necessary for starch formation in green plants. What is carbon dioxide 'snow' and why is it used by the ice cream vendor to keep the ices solid? [Lond.]

9. Describe what may be seen, and explain the changes that occur, when the following substances are (separately) exposed to moist air for some time: (a) quicklime, (b) caustic soda, (c) anhydrous copper sulphate, (d) iron. [C.W.B.]

10. Differentiate clearly between mixtures and compounds, illustrating your answer with *two* distinct examples of each class. Give an account of the methods (*one* in each case) which you would employ in an attempt to determine whether (a) a given clear liquid, and (b) a given powder, were mixtures or compounds. Suggest (without describing in detail) *one* method by which you could free the exhaust gases of a motor car from the carbon dioxide which they contain. [N.J.B.]

11. Write an essay on the gas carbon dioxide, dealing briefly with the following topics: (a) its occurrence and importance in nature; (b) its occurrence as a by-product of industrial processes; (c) the methods of manufacture on a commercial scale, and the forms in which it is normally purchasable; (d) its practical uses. [N.J.B.]

12. Describe in detail, with the aid of a diagram, an experiment to show that although a lighted candle may appear to 'burn away' the matter of which it is composed is not destroyed. [N.J.B.]

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